Search for H^+ and H^{++} bosons with the CMS detector

Nuno Almeida – LIP Lisbon
(On behalf of CMS collaboration)

Supersymmetry 2011
28 Aug- 02 Sept Fermilab

Outline

- Theoretical Overview
- Search for singly charged Higgs boson
- Search for doubly charged Higgs boson
- Summary

H^+ search in Top quark decay

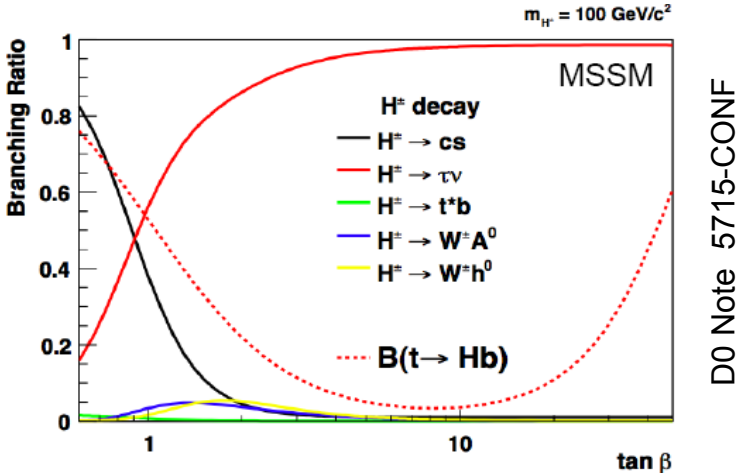
Ref: CMS-PAS-HIG-11-008

- Charged Higgs boson is predicted by extensions of Standard Model with two Higgs doublets, such as MSSM **(5 higgs predicted : H,h, A and $H^\pm$)**

- Production and decay at tree level depends on M_A and $\tan\beta = v_1/v_2$

Light H+ ($m_{H+} < m_{top}$) : $pp \to t\bar{t} \to H^\pm b W^\mp \bar{b}$

Heavy H+ ($m_{H+} > m_{top}$) : $pp \to tH^\pm \ (tbH^\pm)$



D0 Note 5715-CONF

Search assumptions :

$m_{H+} < m_{top}$, $H^+ \to \tau\nu$, $BR(H^+ \to \tau\nu) = 1$ (high $\tan\beta$)

Three channels included :

1) Hadronic tau decay, hadronic W decay (τ_{had} + jets) : $H^\pm \to \tau_h \nu, W^\mp \to q_i \bar{q}_j$

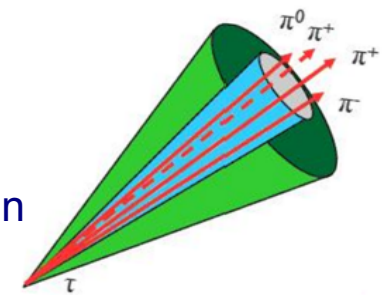
2) Hadronic tau decay, leptonic W decay (τ_{had}+μ) : $H^\pm \to \tau_h \nu, W^\mp \to \mu\nu$

3) Leptonic tau decay, leptonic W decay (e + μ) : $H^\pm \to \tau\nu, \tau \to e(\mu)\nu, W^\mp \to \mu(e)\nu$

Tau reconstruction in CMS

Ref: CMS-PAS-TAU-11-001

- Experimental signature of **hadronically-decaying taus** (τ_{had}) is a collimated jet of up to three charged particles and photons from π^0's decay.

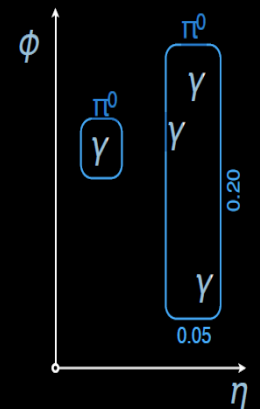


- Tau reconstruction **(HPS algorithm)** uses **Particle Flow** objects, with selection applied on isolation (loose,medium,tight working points), mass and collimination. Additional selections applied to reject electrons and muons

Hadrons Plus Strips Algorithm

build signal components combinatorially

cluster gammas into π^0 candidates using η-ϕ strips



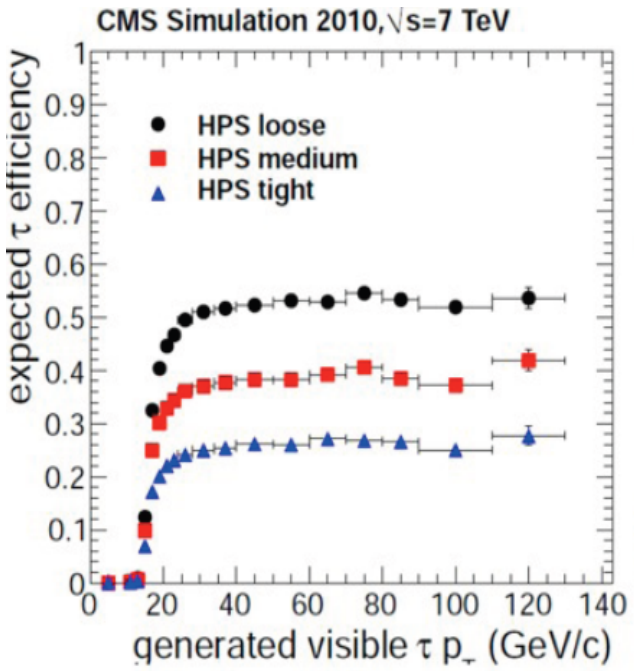
build all possible taus that have a 'tau-like' multiplicity from the seed jet

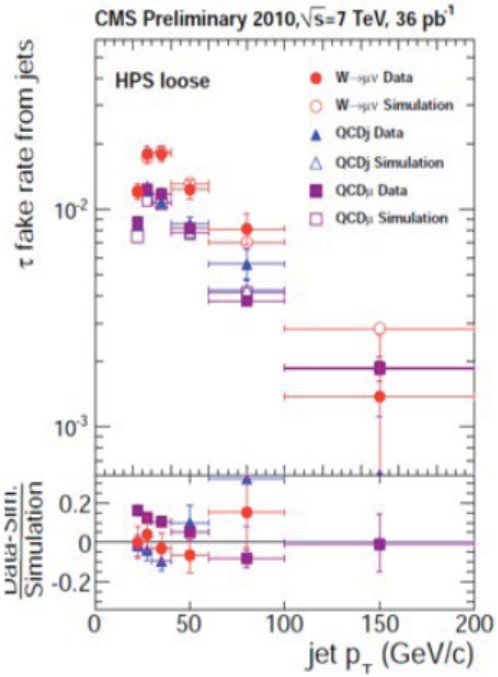
π^+

$\pi^+ \pi^0$

$\pi^+ \pi^+ \pi^-$

tau that is 'most isolated' with compatible m_{vis} is the final tau candidate associated to the seed jet



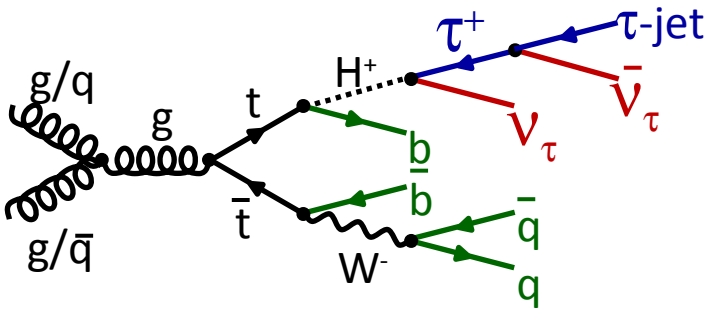


Fully hadronic final state

1.08 fb-1 of data used

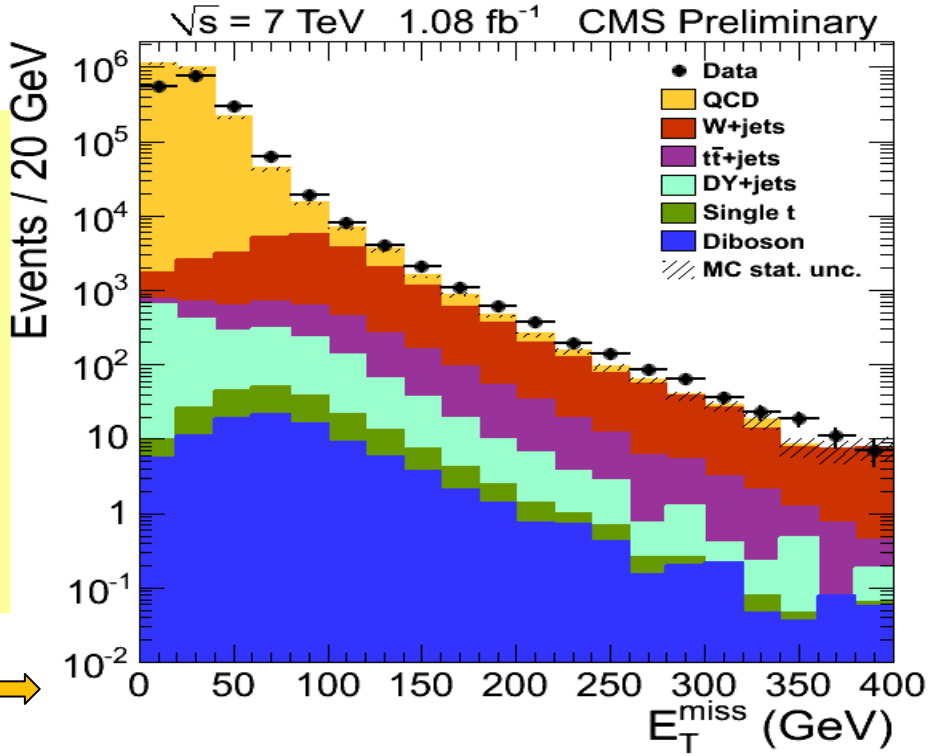
Main backgrounds: QCD multi-jet, $t\bar{t}$, W+jets

General selection strategy: suppress QCD multi-jet background below $t\bar{t}$ and other backgrounds



Event Selection :

- Trigger: Single tau + E_T^{miss} trigger
- One tau : **1 prong , p_T > 40 GeV/c,**
  p_T(leading particle)>20 GeV/c, tight isolation
- E_T^{miss} > 70 GeV
- At least 3 jets, p_T > 30 GeV/c, $|\eta| < 2.4$
- At least one b-jet



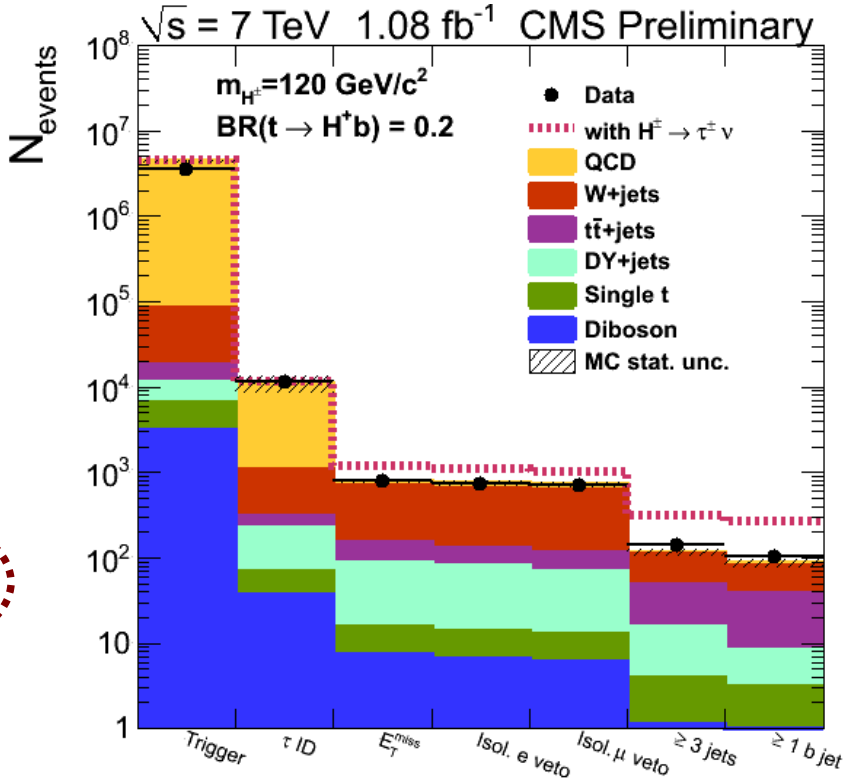
After all selections except
Tau isolation and b-tagging

Fully hadronic event yields

Summary of event yields after final selection

Source	N_{events}
HH+HW, $m_{H^\pm} = 120\,GeV/c^2$, BR=0.2	121 ± 6 (stat.) ± 39 (syst.)
QCD multi-jets	7.5 ± 0.5 (stat.+syst.)
EWK+$t\bar{t}$ τ	71 ± 5 (stat.) ± 16 (syst.)
EWK+$t\bar{t}$ τ fakes	3.5 ± 0.8 (MC stat.) ± 1.0 (syst.)
Total expected from the SM	82 ± 5 (stat.) ± 16 (syst.)
Data	104

Major bakgrounds measured from data :



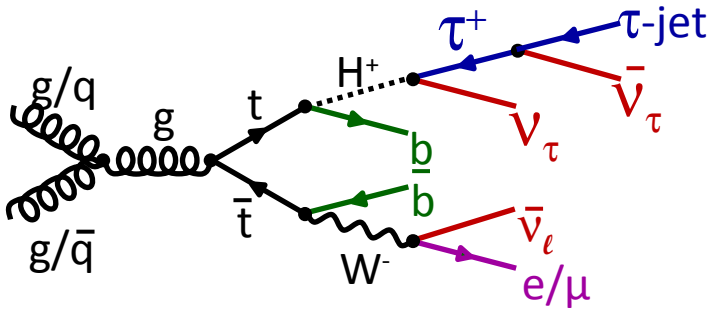
- QCD multijet background estimation uses factorisation of E_T^{miss} + b-tagging sel. efficiencies
- EWK + $t\bar{t}\tau$ taken from data using embedding simulated taus in muon events

Data agrees well with the SM expectations within the uncertainty
NO excess observed !

Muon + Hadronic tau decay

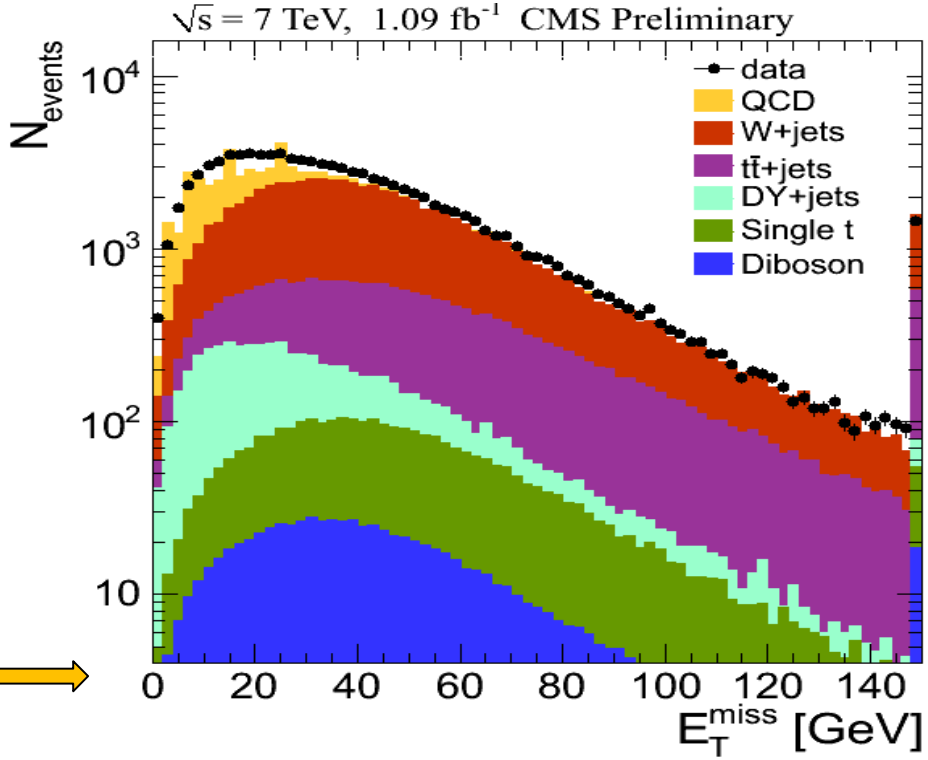
1.09 fb-1 of data used

Main backgrounds : $t\bar{t}$,W+jets



Event Selection :

- Iso. single muon trigger (p_T > 17 GeV/c)
- One isolated muon p_T >20 GeV/c
- At least 2 jets p_T>30 GeV/c
- E_T^{miss} > 40 GeV
- One tau : **p_T >20 GeV/c, loose isolation**
- Opposite-Sign between muon and tau
- At least one b-jet



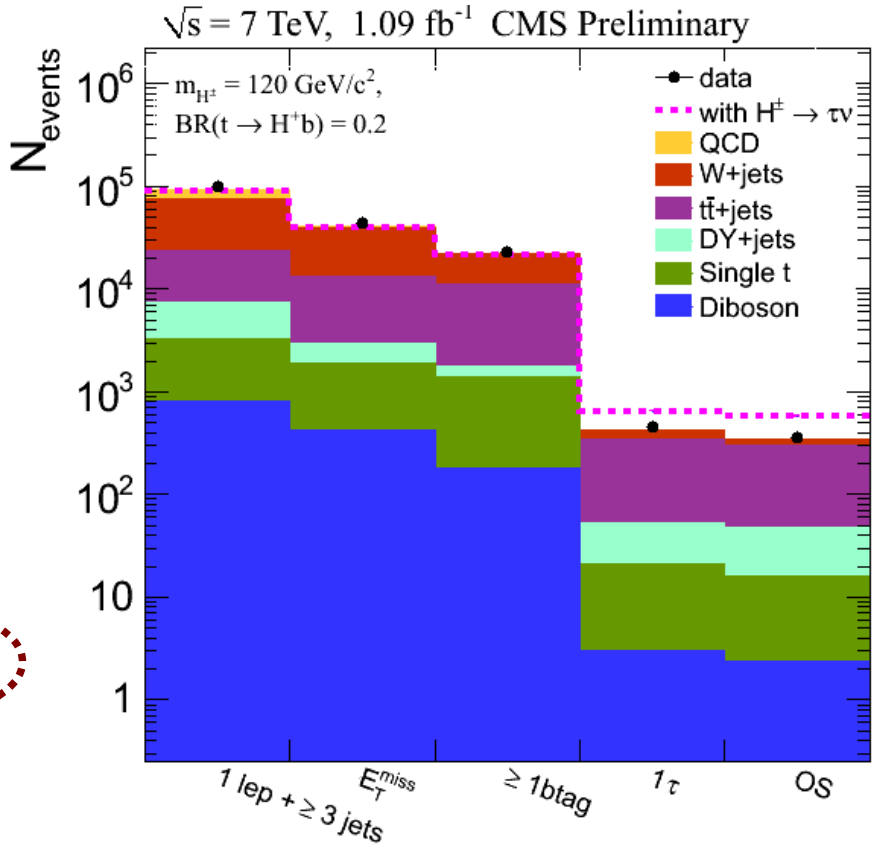
After selections of one muon and 2 jets

Muon + hadronic tau decay event yields

Summary of event yields after final selection

Source	$N_{events} \pm$ stat. $\pm$ syst.
HH+HW, m_{H^+}=120 GeV/c^2, BR=0.2	$323 \pm 8.7 \pm 67$
τ fakes	$163.0 \pm 9.7 \pm 17.3$
$t\bar{t} \to WbWb \to \ell\nu b\, \tau\nu b$	$152.7 \pm 2.8 \pm 35.0$
$t\bar{t} \to WbWb \to \ell\nu b\, \ell\nu b$	$13.2 \pm 0.8 \pm 3.5$
$Z/\gamma^* \to ee, \mu\mu$	$0.7 \pm 0.5 \pm 0.5$
$Z/\gamma^* \to \tau\tau$	$30.9 \pm 3.6 \pm 6.0$
Single top	$13.8 \pm 0.7 \pm 2.1$
VV	$2.4 \pm 0.2 \pm 0.4$
Total expected from the SM	$376.7 \pm 10.8 \pm 39.7$
Data	361

Background measured from data with tau fake rate method



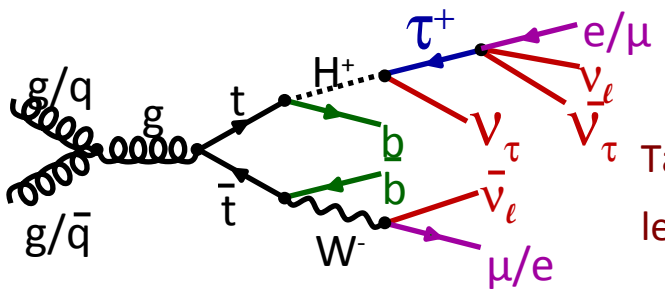
Data agrees well with the SM expectations within the uncertainty
NO excess observed

eμ final state

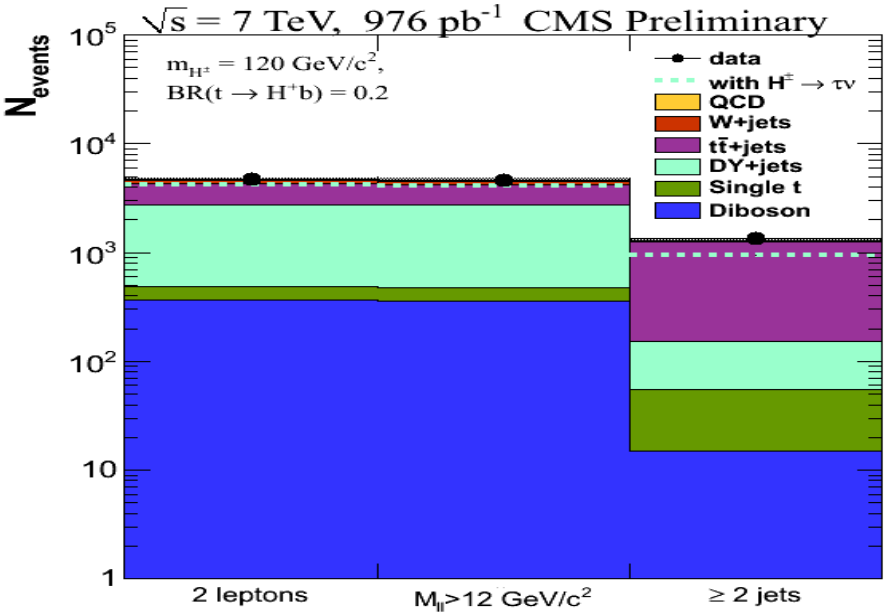
0.98 fb-1 of data used

Summary of event yields after final selection

Source	$N_{events} \pm$ stat. $\pm$ syst.
HH+HW, m_{H^+}=120 GeV/c^2, BR=0.2	$219 \pm 7 \pm 43$
$t\bar{t}$	$1094 \pm 6 \pm 219$
$Z/\gamma^* \rightarrow ll$	$98 \pm 3 \pm 12$
W+jets	$18 \pm 3 \pm 2$
Single top	$40 \pm 1 \pm 4$
VV	$14.7 \pm 0.4 \pm 1$
Total expected from SM	$1264 \pm 7 \pm 219$
Data	1340



Tau decays leptonically



Main background : $t\bar{t}$

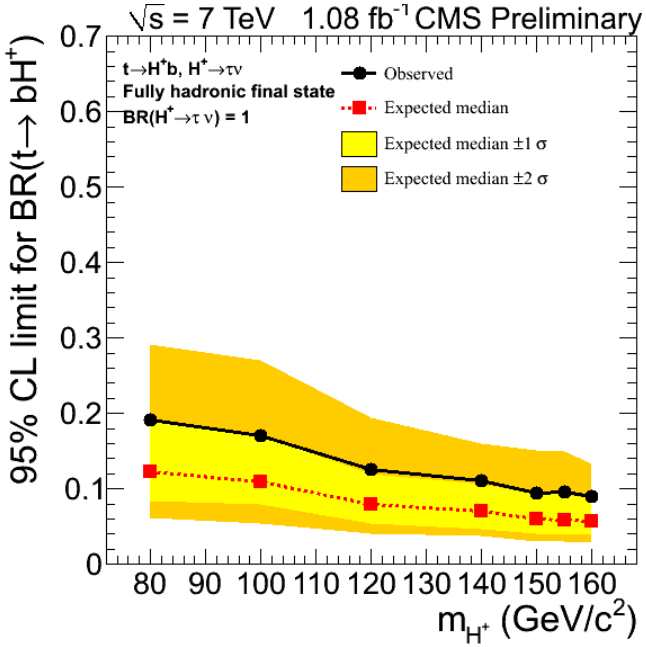
Event Selection :

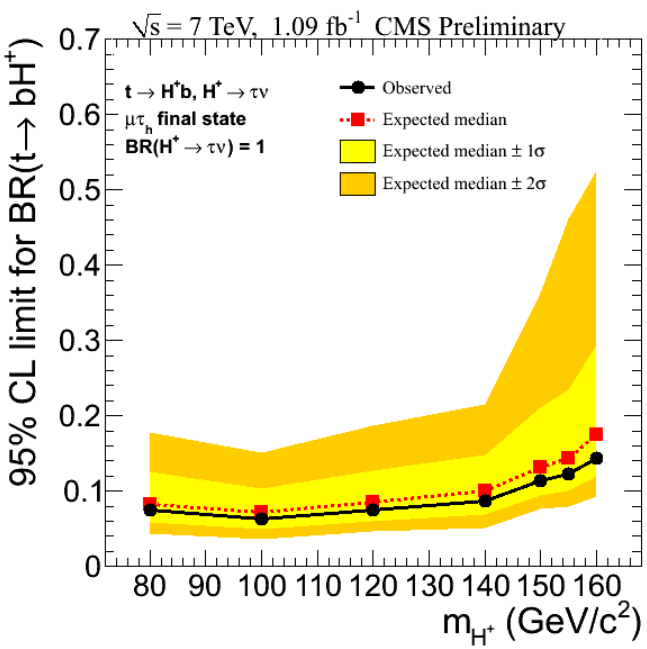
- e-μ trigger
- One isolated e (p_T>20 GeV/c)
- One isolated μ (p_T>20 GeV/c)
- At least 2 jets (p_T>30 GeV/c)

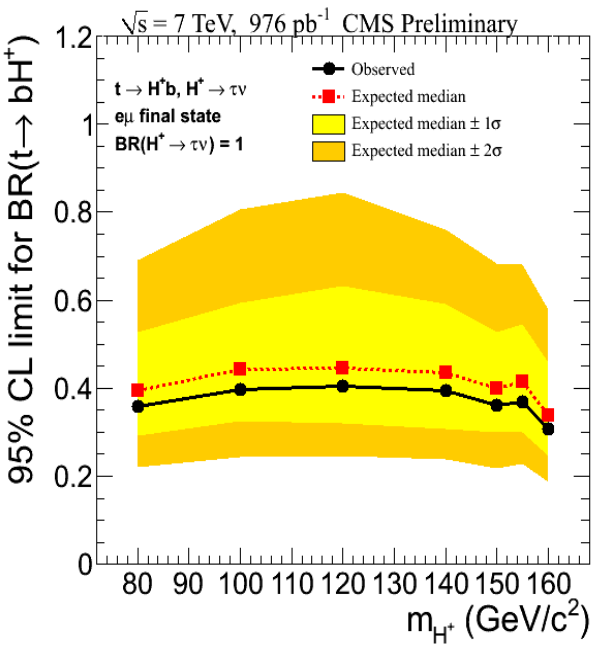
Deficit of total events expected in the presence of charged Higgs boson, because e/μ from τ decay become soft

Upper limit on BR ($t \rightarrow H^+b$)

fully hadronic | **muon+tau** | **electron+muon**







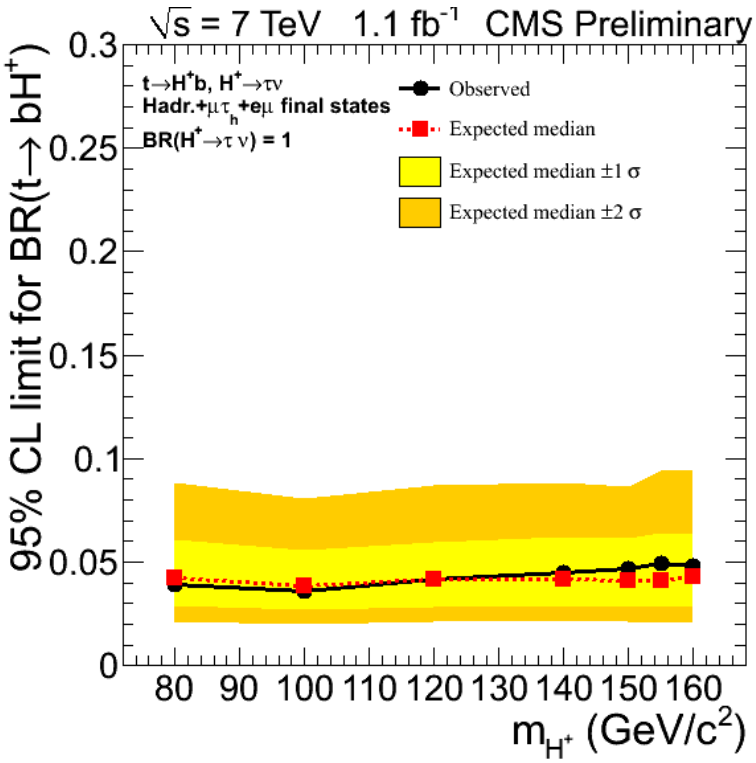
95 % CL upper limit on BR($t \rightarrow H^+b$) using CLs method.

The signal is modelled as the excess (or deficit) of events yields in presence of H^+

$$N_{excess\ (deficit)} = N_{tt}^{SUSY} - N_{tt}^{SM} = N_{WH}\, 2(1-x)x + N_{HH}\, x^2 + N_{tt}^{SM}\, ((1-x)^2 - 1)\ ,\ x = BR(t \rightarrow H^+b)$$

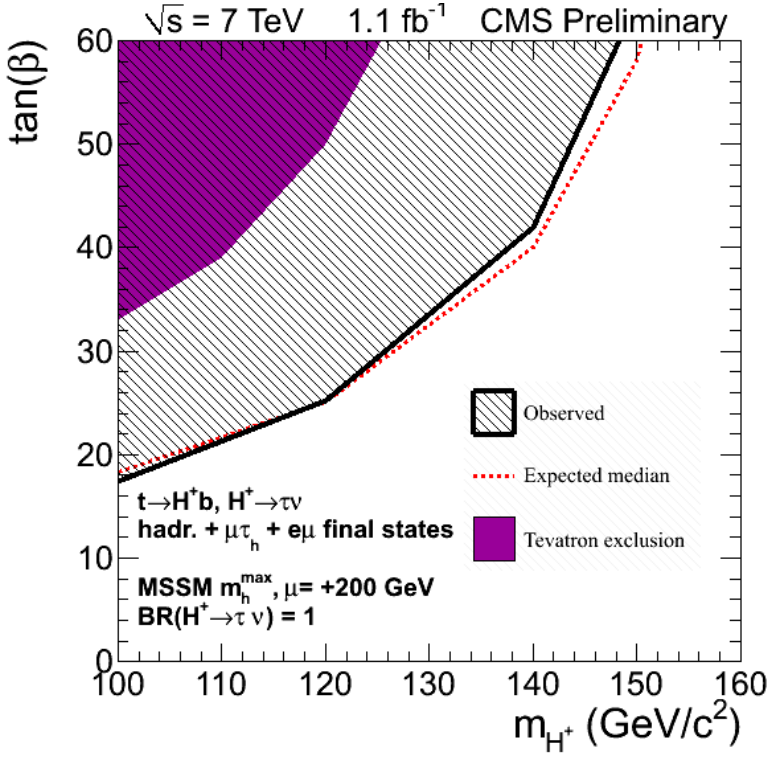
Results from Combination

combination of the fully hadronic, muon + tau and electron + muon channels



Tevatron limit : 0.15 – 0.2

V.M. Abazov et al.
Phys.Lett.B682:278-286,2009
arXiv:0908.1811



exclusion region in MSSM (m_h^{max})

MH^+-tanβ parameter space

Doubly charged Higgs boson (Φ^{++})

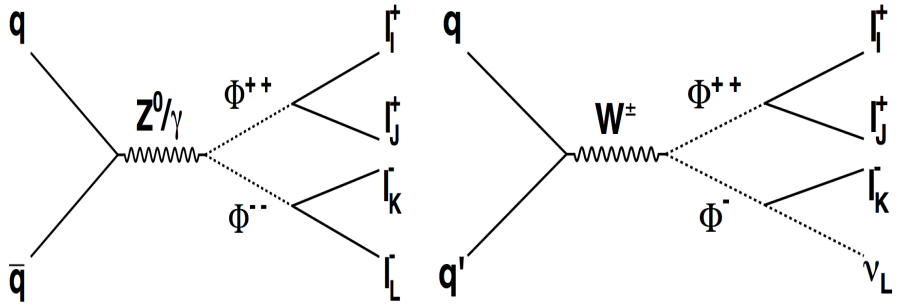
Ref: CMS-PAS-HIG-11-007

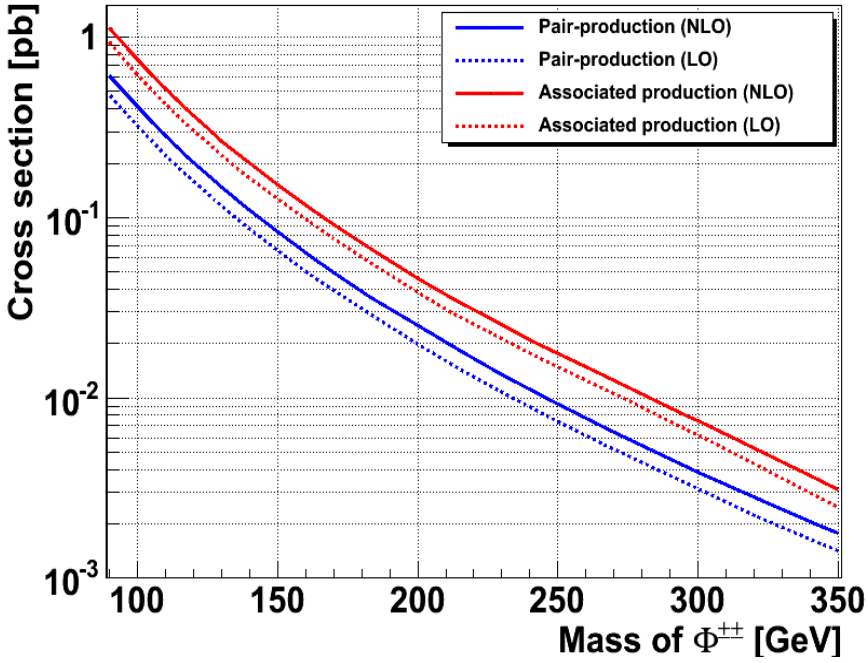
- Standard model extension by a scalar triplet adding three new particles
  - Φ^{++}, Φ^{+}, Φ^{0} **(type-II seesaw model)**
- Triplet responsible for neutrino masses, the couplings being directly linked to the mass matrix
- Unknown neutrino mass matrix
  - unknown branching ratios
  - we assume decays to leptons only
- Six standard searches covered, where

BR($\Phi^{++}\rightarrow l^{+}l^{+}$)=100%

- **Four additional model dependent points** to describe the neutrino sector with different mass hierarchies

$pp \rightarrow \Phi^{++}\Phi^{--} \rightarrow \ell_i^+\ell_j^+\ell_k^-\ell_l^-$ $pp \rightarrow \Phi^{++}\Phi^{-} \rightarrow \ell_i^+\ell_j^+\ell_k^-\nu_l$

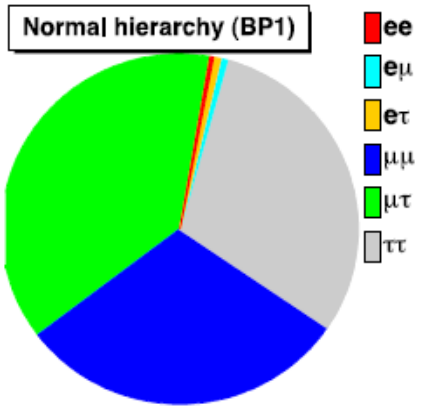


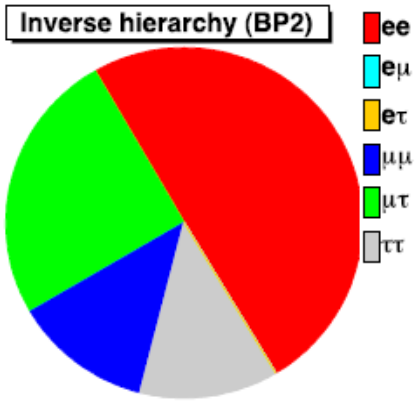


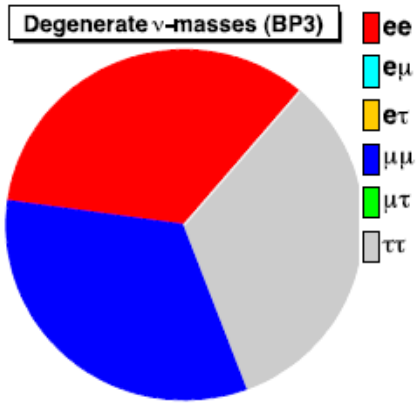
Model Points

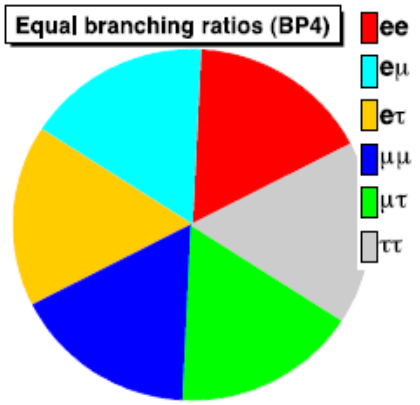
Four additional model dependent points :

- BP1 describes the neutrino sector with **normal mass hierarchy** and a massless lightest neutrino, $m_1 = 0$ eV
- BP2 describes the same but with the **inverse mass hierarchy**
- BP3 represents a **degenerate neutrino mass spectrum** with $m_1 = 0.2$ eV
- BP4 represents the **degenerate case in which all Φ^{++} branching fractions are equal**









Φ^{++} analysis in a nutshell

0.98 fb-1 of data used

- **Signatures: 3 or 4 leptons** in the final state, **dilepton made by same sign lepton**
- **Backgrounds:** ZZ, WZ , Z+jets, $t\bar{t}$+jets, (W+jets, QCD)

Selection Strategy:

- Dilepton triggers
- Lepton id, tight isolation, charge matching
- Σp_T cuts on leptons
- Z mass veto
- Cut $\Delta\phi$ between leptons

Pre-selection:

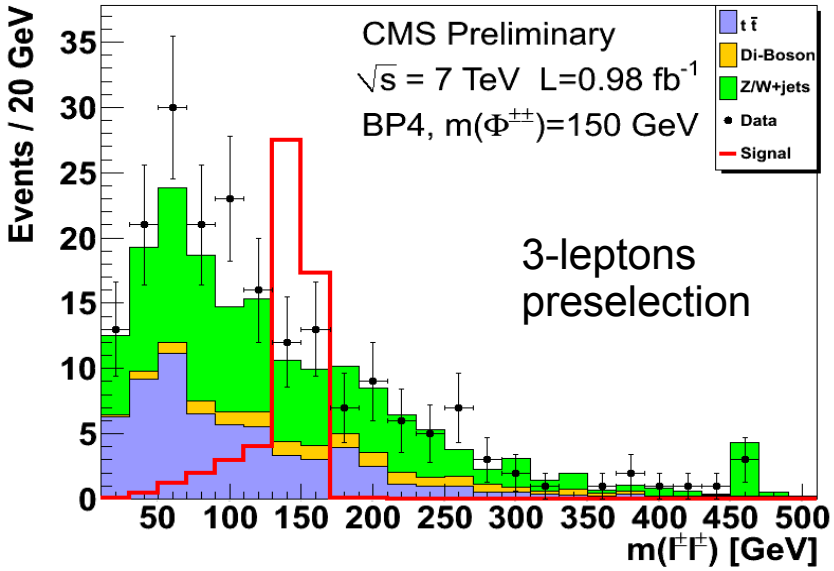
- At least two leptons with p_T > 35 / 10 GeV/c
- Loose isolation requirement
- Veto of low invariant mass resonances (< 12 GeV)

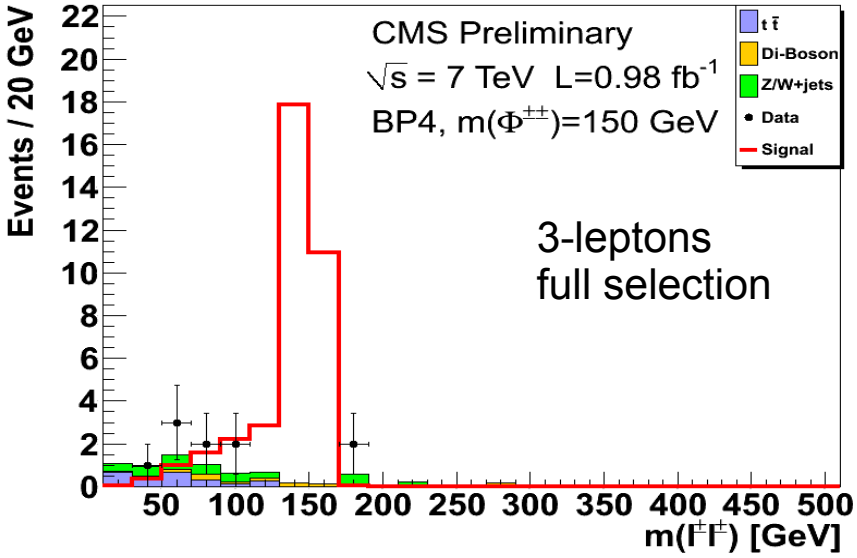
Additional topological cuts on leptons depending on final states with three or four leptons

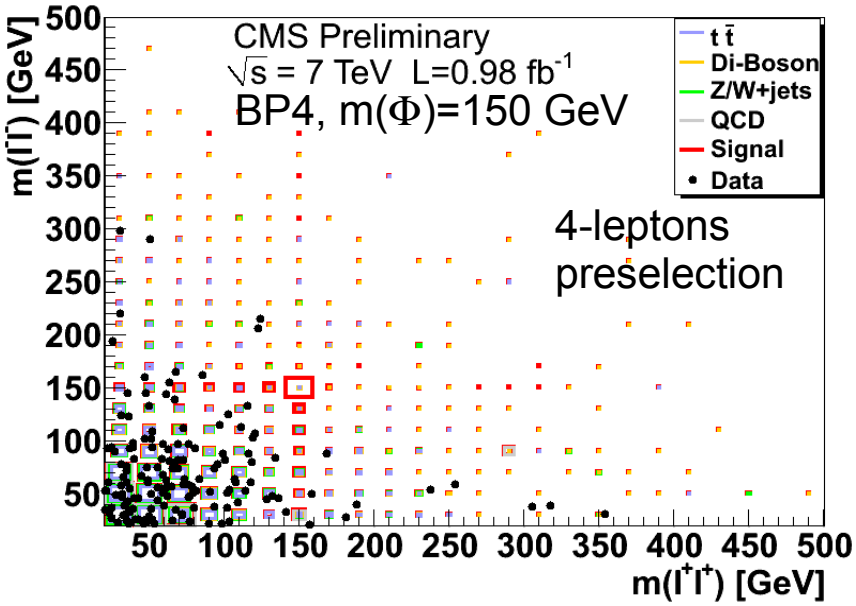
- Events are counted in the mass window depending on the Higgs boson mass considered

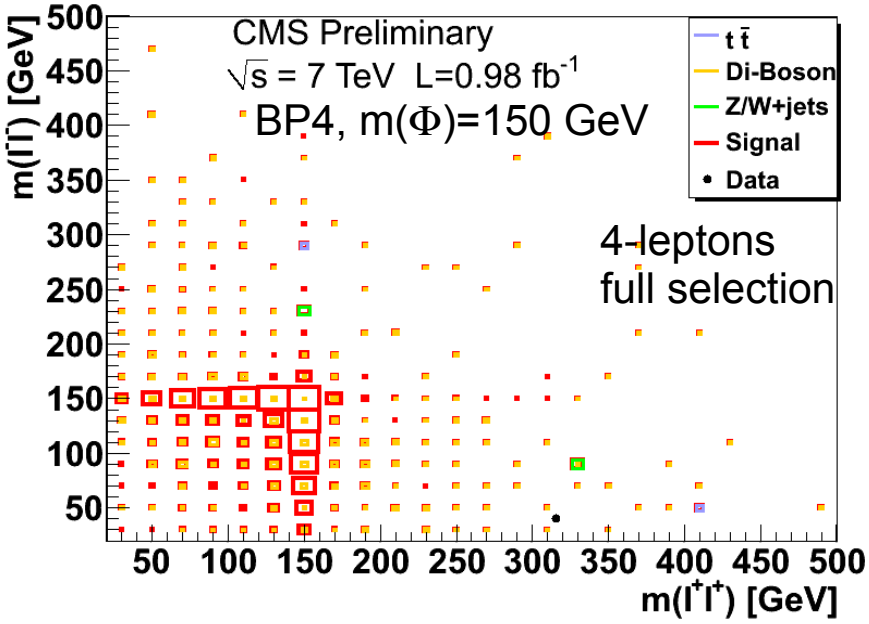
- **Control from real data of** the lepton-related efficiencies, background estimation is driven from data using the sidebands method
- **Inclusive search** in order to cover the whole phase space.

Invariant Mass Reconstruction

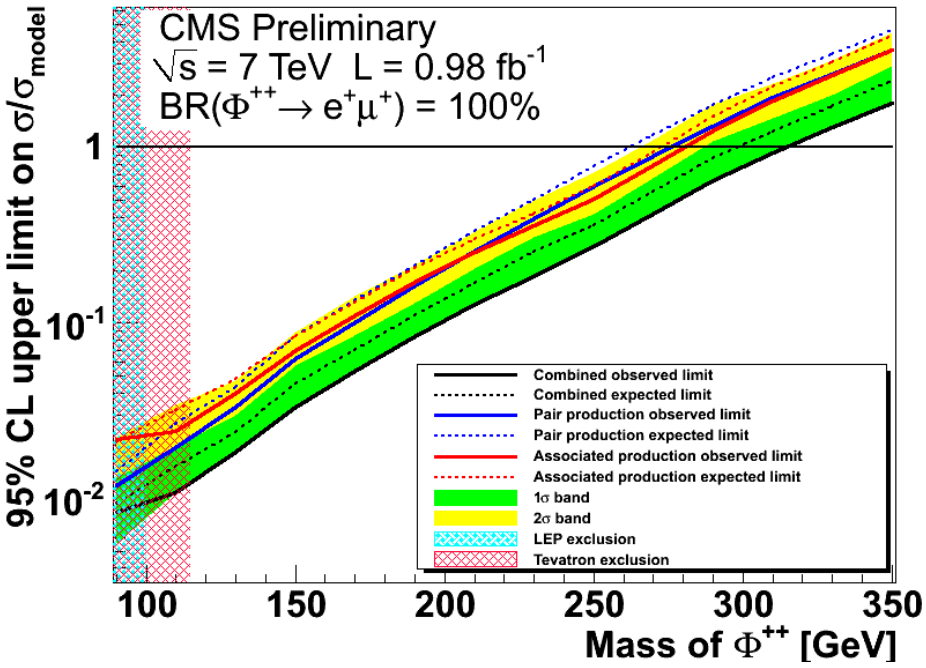


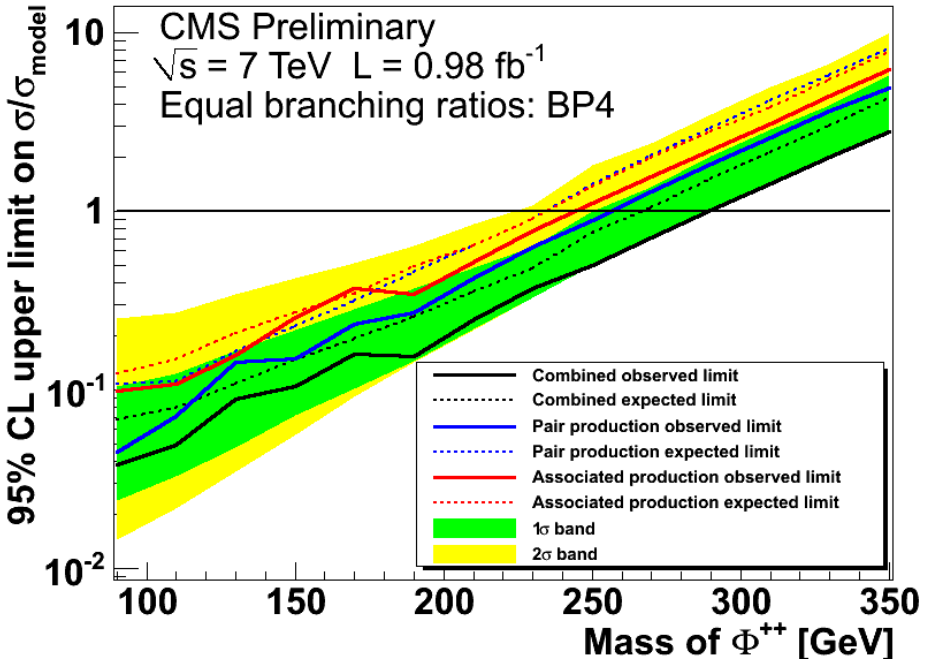






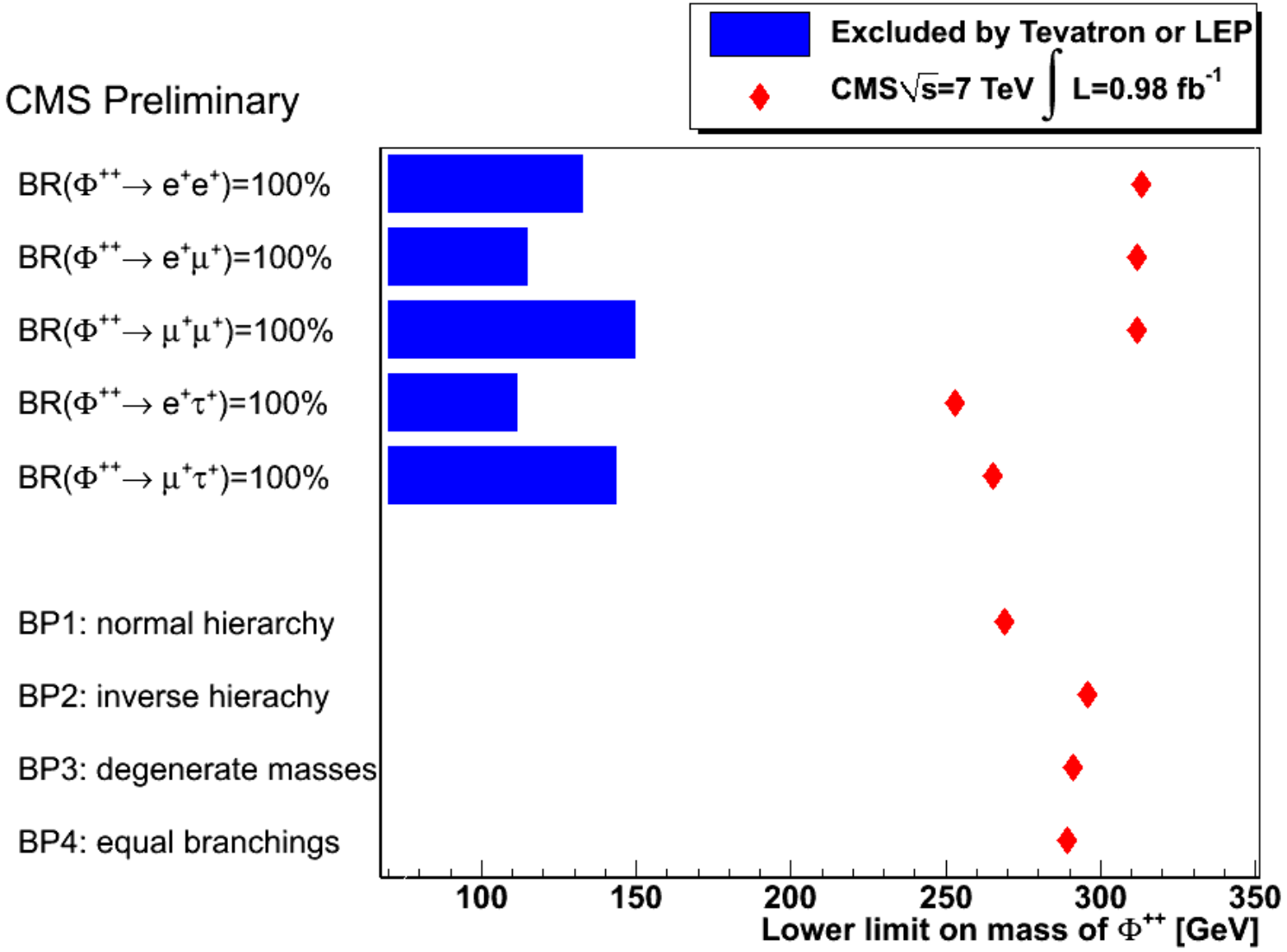
Lower limit on Φ^{++}





95% CL lower Limits obtained using CLs method

Lower limit on Φ^{++}



Summary

H+ and Φ^{++} analysis performed with ~1 fb^{-1} of 2011 CMS data

H^+ search :

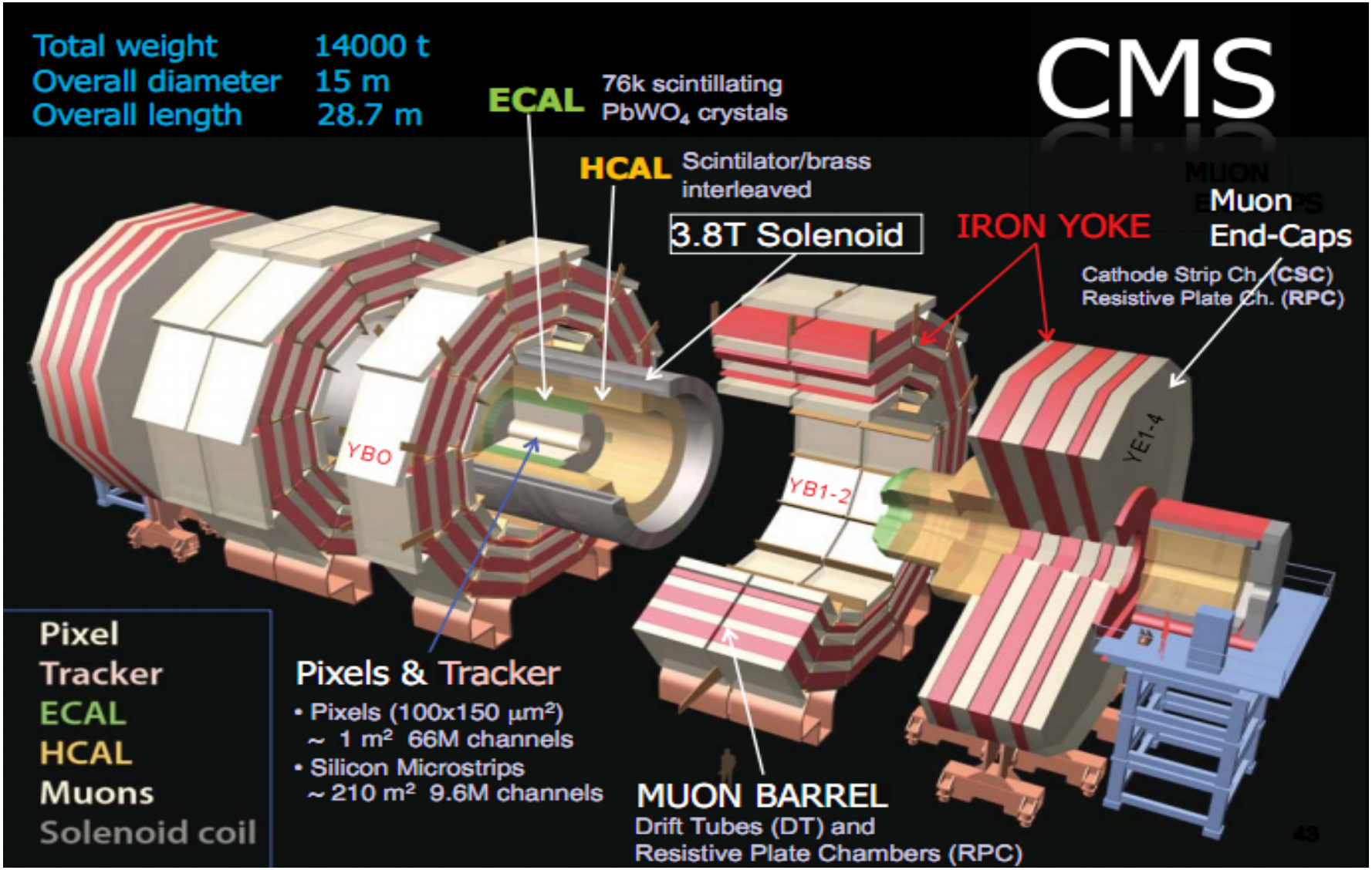
- Three channels included (fully hadronic, $\mu+\tau_{had}$, $e+\mu$)
- No excess of events observed
- Upper limits of 4-5 % placed on BR($t \rightarrow H^+ b$) in mass range of 80-160 GeV

Φ^{++} search :

- A fully inclusive search has been performed with no excess observed
- CMS has the best limits in most of channels

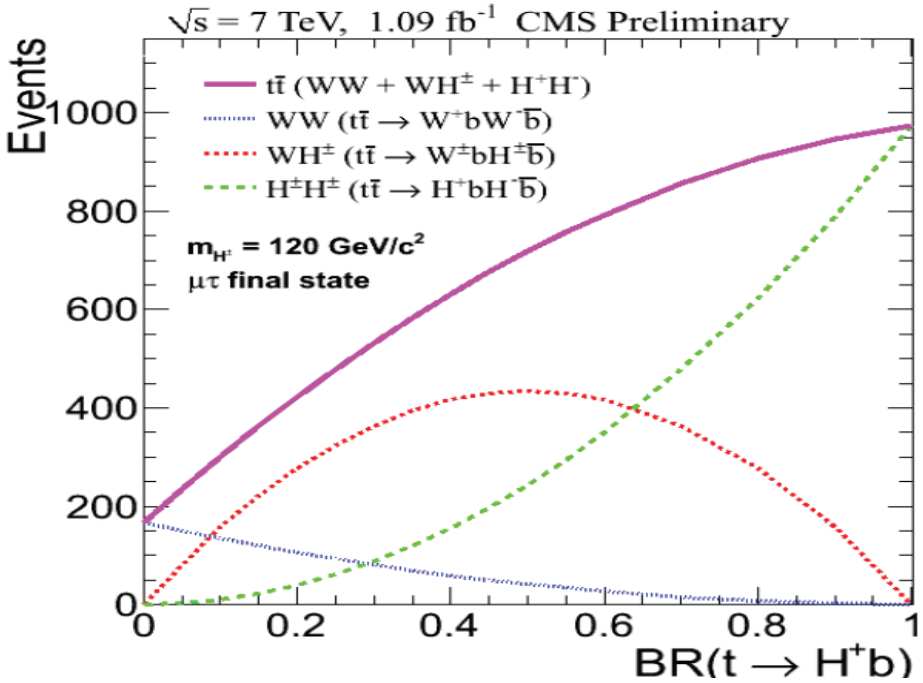
Backup Slides

The Compact Muon Solenoid

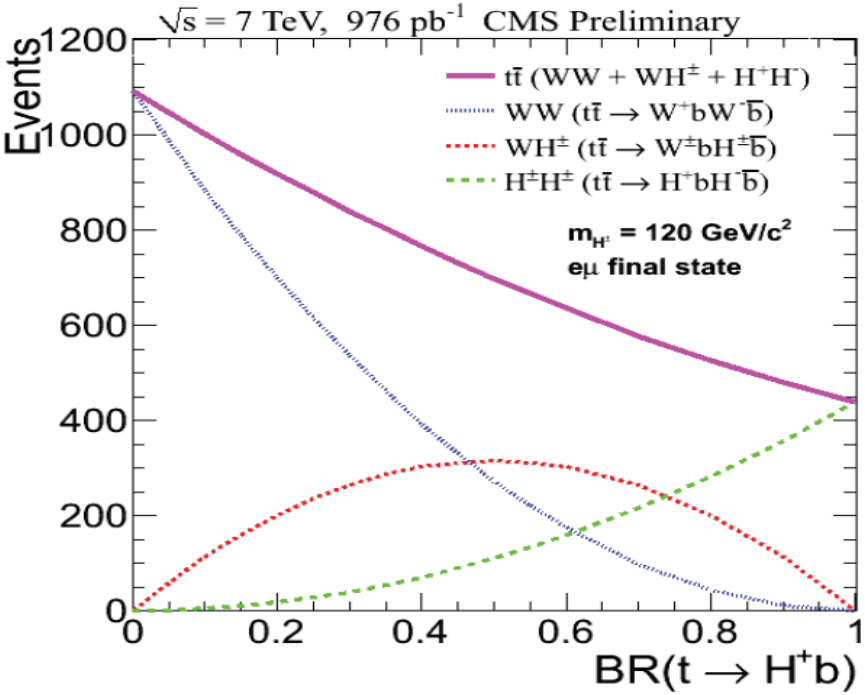


Expected events vs BR

muon+tau



e+muon



$x = BR(t \rightarrow bH^+)$

N_{tt} (in presence of H^+) = $N_{WH}\, 2(1-x)x + N_{HH}\, x^2 + N_{tt}^{SM}\, (1-x)^2$

Background measurements in fully hadronic final state

QCD multi-jet background, **measured from data**

Method based on factorisation of E_T^{miss} + b-tagging from other selections

Apply same selections like signal analysis but in different order.

Factorize $\varepsilon(E_T^{miss}$ + b-tagging) at a selection level where QCD contribution dominates.

ε (E_T^{miss} + b-tagging) estimated in bin of τ p_T.

➢ EWK+$t\bar{t}\tau$ background (genuine taus within p_T, η acceptance), **measured from data**

Based on tau embedding method

Select events with only one isolated lepton (p_T > 40 Gev/c, $|\eta|$ < 2.1) and 3 jets (p_T > 30 GeV/c, $|\eta|$ < 2.4). Replace the muon by a fully simulated and reconstructed tau with same momentum.

➢ EWK+$t\bar{t}\tau$ fakes background (e/μ/jets mis-identified as taus, or genuine taus outside p_T, η acceptance)

Expected to be small, **estimated from simulation**

QCD multi-jet background

- Same selections like in signal analysis, but applied in different order to select from data sample where QCD multi-jets dominate
- Number of events in signal region estimated with

$$N_{QCD} = \Sigma_i N_{selected,i}^{data} \times f_{presel,i} \times \varepsilon_{MET+b,i}^{data},$$

where i is tau p_T bin and f fraction of QCD multi-jet events

	Number of events
MC expectation	7.4 ± 0.3
data estimate	7.5 ± 0.5 (stat.+syst.)

- **Tau+MET trigger**
- **Tau candidate selection**
  - Trigger matching, jet p_T>40 GeV/c, $|\eta|$<2.1, ldg. track p_T>20 GeV/c, e/μ veto, select exactly one tau cand.
- **Veto of isolated electrons muons (p_T>15 GeV/c) and muons (p_T>15 GeV/c)**
- **Jet selection:**
  - $N_{jets} \geq 3$ with E_T>30 GeV and $|\eta|$<2.4 in addition to the tau candidate, $\Delta R(\tau, jet)$<0.5

$\varepsilon_{MET+b\text{-}tag,i}^{data}$

- Factorize out MET+ b-tagging cuts in bins of tau candidate p_T (MET>70)
- Sample purity 60-90 %

- tau ID (HPSTight isolation && Nprongs=1)

$N_{selected,i}^{data}$

- Number of events after tauID
- Sample purity 50-90 %

EWK+$t\bar{t}\tau$ background (genuine taus) data-driven

- **Control sample selection**
  - → One muon, $p_T > 40$ GeV/c, $|\eta| < 2.1$
    - •Isolation by requiring no HPSTight-quality PFCandidates in $0.1 < \Delta R < 0.4$
  - → Veto of isolated electrons and other muons, $p_T > 15$ GeV/c
  - → At least 3 PF jets, $p_T > 30$ GeV/c, $|\eta| < 2.4$
- **Tau embedding at PF level**

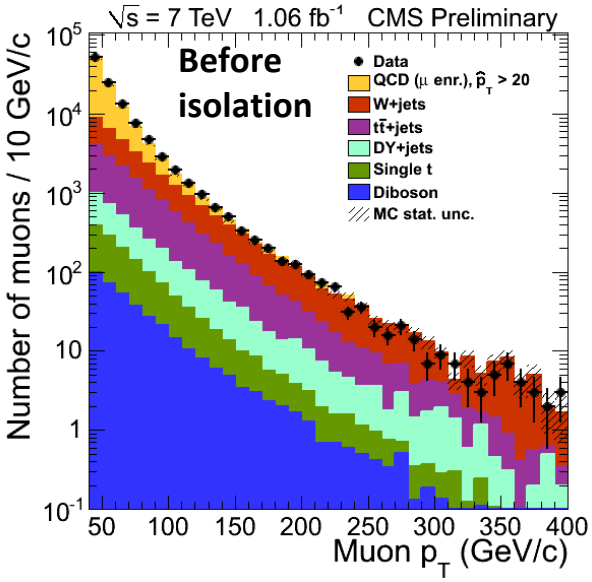
Simulate and reconstruct tau with same momentum as muon

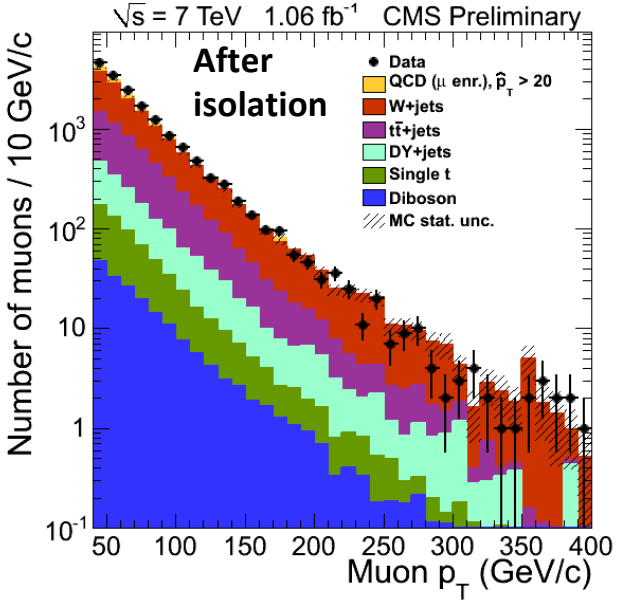
- **Normalisation**
  - → Tau trigger efficiency with weighting by efficiency
  - → MET trigger efficiency with

"vector sum caloMETnoHF" > 60 GeV

  - → Muon trigger and ID efficiency with Tag and Probe

Result: 71 ± 5 (stat) ± 15 (syst)
MC expectation: 78 ± 7 (stat)





Systematics (Fully Hadronic)

Table 1: The systematic uncertainties (in %) for the backgrounds and the signal from $t\bar{t} \to H^{\pm}bH^{\mp}\bar{b}$ (HH) and $t\bar{t} \to W^{\pm}bH^{\mp}\bar{b}$ (WH) processes at $m_{H^{\pm}}$=80-160 GeV/c^2.

	HH	WH	QCD	EWK+$t\bar{t}$ τ	EWK+$t\bar{t}$ τ fakes				
					$t\bar{t}$	tW	W+jets	Z+jets	VV
$\tau - p_T^{miss}$ trigger	24–26	24–25		9.6	22	22	22	24	23
τ-jet id	7.0	7.0		7.0					
jet, $\ell \to \tau$ mis-id					15	15	15	15	15
JES+JER+MET	13–17	14–19		18	17	25	14	19	22
lepton veto	0.2–0.3	0.3–0.4			1.5	0.6	0.6	0.6	0.7
b-jet tagging	12–15	14-16			16	17			
jet$\to$b mis-id							13	10	11
QCD stat.+syst.			7.1						
EWK+$t\bar{t}$ τ stat.				6.8					
$f_{W\to\tau\to\mu}$				0.7					
muon selections				0.6					
MC stat	4.1–7.0	4.8–7.2			16.3	56	100	100	90
cross-section	20	20			20	8	5	4	4
luminosity	6.0				6.0				

Background estimate in muon + tau final state

Main background from "fake" tau jets

major contribution : W+jets, $t\bar{t} \rightarrow \ell$ + jets

Data driven background estimation :

- Select jets in events with :

  1 lepton + MET + ≥3 jets

  + ≥ 1 b-tagged jet

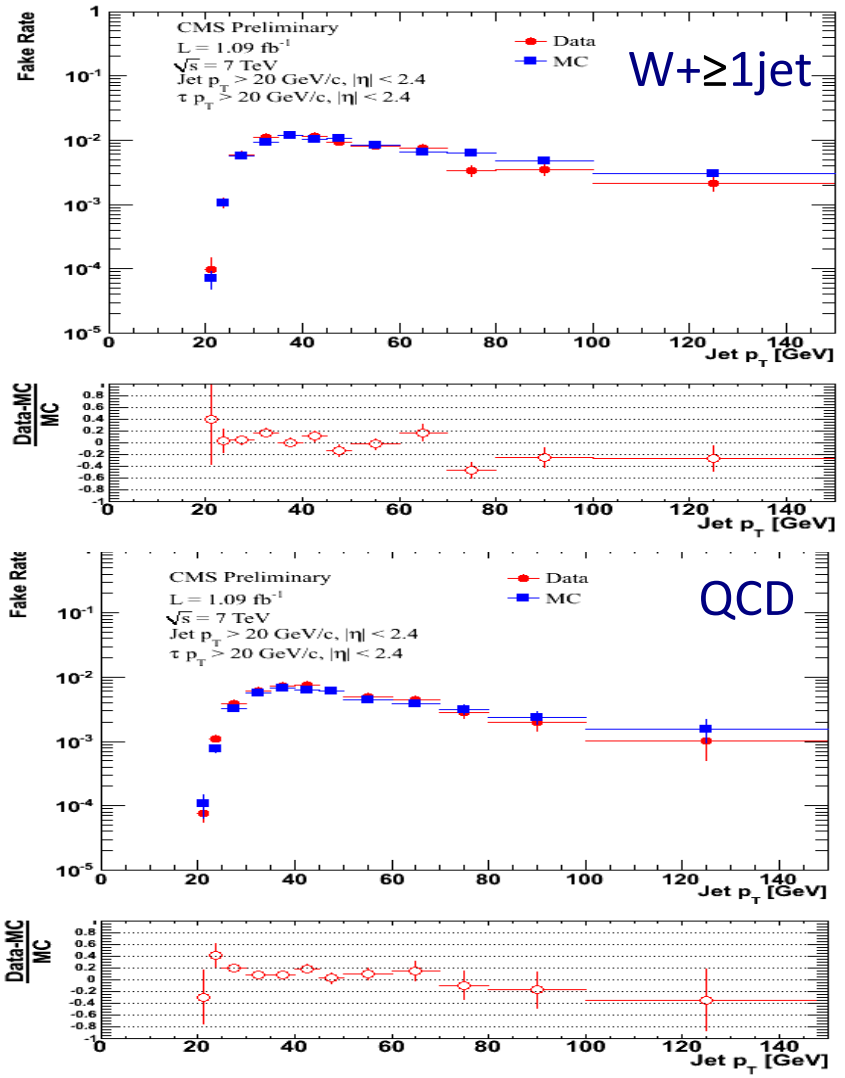
- Apply to every jet a

"jet→ τ probability (pt,eta,jet width)"

Jet width = $\sqrt{(\sigma_{\eta\eta}^2 + \sigma_{\phi\phi}^2)}$

Jet → τ probability measured from data from different type of samples

(QCD dijets, W + ≥1 jets)



Systematics

mu+tau channel

	HH	WH	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	τ fakes	Single top	VV	DY($\mu\mu$)	DY($\tau\tau$)
τ-jet id	7.0	7.0	7.0			7.0	7.0		7.0
jet, $\ell \rightarrow \tau$ mis-id				15.0				15.0	
JES+JER+MET	6.0	4.0	3.0	3.0		8.0	8.0	71.0	14.0
b-jet tagging	6.0	6.0	5.0	5.0		8.0			
jet$\rightarrow$b mis-id							8.0	9.0	9.0
muon selections	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0
τ fakes (stat)					6.0				
τ fakes (syst)					11.0				
cross-section	20.0					8.0	4.0	4.0	
MC stats	3.0	3.0	2.0	6.0		5.0	8.0	71.0	12.0
luminosity	6					6			

e-mu channel

	HH	WH	$t\bar{t}$	DY(ll)	W+jets	Single top	VV
JES+JER+MET	2.8	2.8	2.8	7.0	6.0	4.9	4.8
dilepton selection	2.5	2.5	2.5	2.5	2.5	2.5	2.5
cross section	20.0	20.0	20.0	4.0	5.0	8.0	4.0
MC stats	7.5	3.4	0.5	3.2	16.0	2.5	2.7
luminosity	6						

Summary of results (95% CL upper limits)

Model point	Former limit	CMS @ 36 pb^{-1}	CMS @ 0.98 fb^{-1}	Only pair-production
BR(Φ^{++}->ee)=100%	133 GeV	144 GeV	313 GeV	274 GeV
BR(Φ^{++}->eμ)=100%	115 GeV	154 GeV	313 GeV	275 GeV
BR(Φ^{++}->$\mu\mu$)=100%	150 GeV	156 GeV	313 GeV	277 GeV
BR(Φ^{++}->eτ)=100%	112 GeV	106 GeV	254 GeV	211 GeV
BR(Φ^{++}->$\mu\tau$)=100%	144 GeV	106 GeV	266 GeV	219 GeV
BP1	N/A	116 GeV	269 GeV	236 GeV
BP2	N/A	131 GeV	297 GeV	263 GeV
BP3	N/A	130 GeV	291 GeV	258 GeV
BP4	N/A	127 GeV	289 GeV	255 GeV

Selection strategy

- Pre-selection:
  - At least two leptons with pT > 35 / 10 GeV
  - Loose isolation requirement
  - Veto of low invariant mass resonances (< 12 GeV)

- Three lepton final state:

Label	Selection
Pre-selection	Correct topology (++- or - -+)
Scalar sum of p_T	$\sum p_T > m(\Phi) + 80\,\text{GeV}$
Relative isolation	$\sum relIso_{lepton} < 0.1$
Veto of events containing a Z boson	$\min\lvert m(\ell^+\ell^-) - m_Z\rvert > 6\,\text{GeV}$
Opening angle between same-sign leptons	$\phi(\ell^\pm\ell^\pm) < 1.8\text{rad}$
Counting of events in a mass window	$m(\ell^\pm\ell^\pm) \in (m_{lower}, m(\Phi)+10\ \text{GeV})$

- Four lepton final state:

Label	Selection
Pre-selection	Correct topology (++- - or - -++) + optional extra leptons
Relative isolation	$\sum relIso_{lepton} < 0.125$
Scalar sum of p_T	$\sum p_T > m(\Phi) + 80\,\text{GeV}$
Counting of events in a mass window	$m(\ell^+\ell^+) \in (m_{lower}, m(\Phi)+10\ \text{GeV})$
	$m(\ell^-\ell^-) \in (m_{lower}, m(\Phi)+10\ \text{GeV})$

The backgrounds have been measured from data extrapolating from sidebands

Background estimation

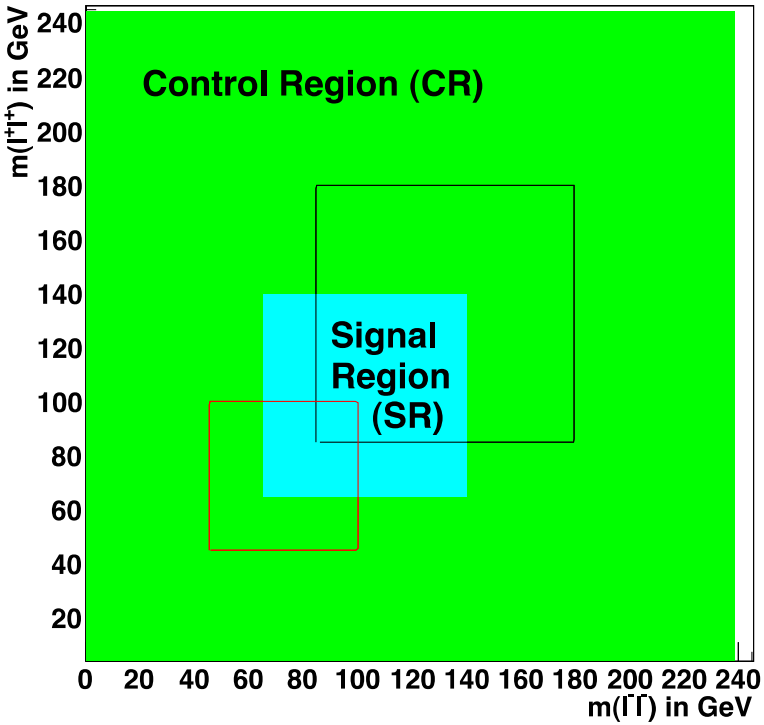
- Background is driven from data using the sidebands method
- Control region is the 1D or 2D (depending if it's 3- or 4-lepton analysis) region in the invariant mass distribution outside search mass window after the tight isolation requirements

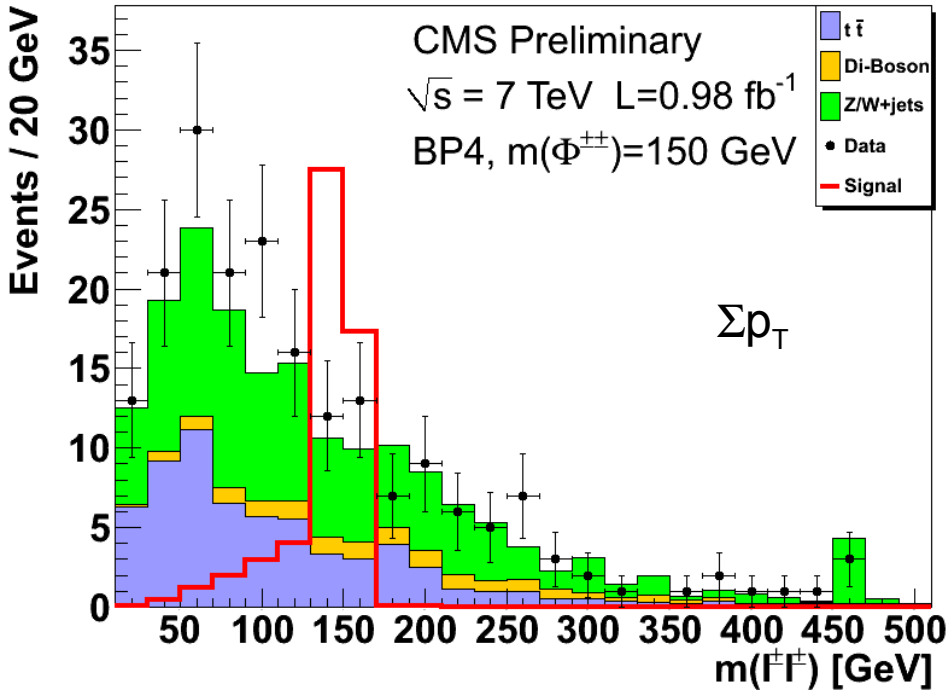
$$\alpha = N_{SR} / N_{CR} \text{ in MC}$$

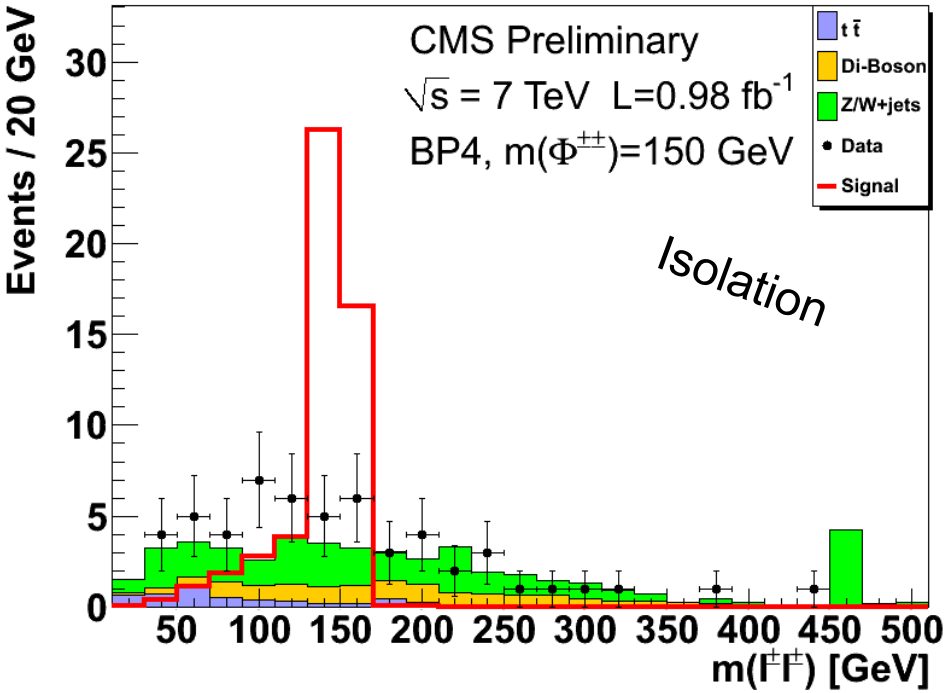
$$N_{BG} = \alpha \, (N_{CR}^{Data}+1)$$

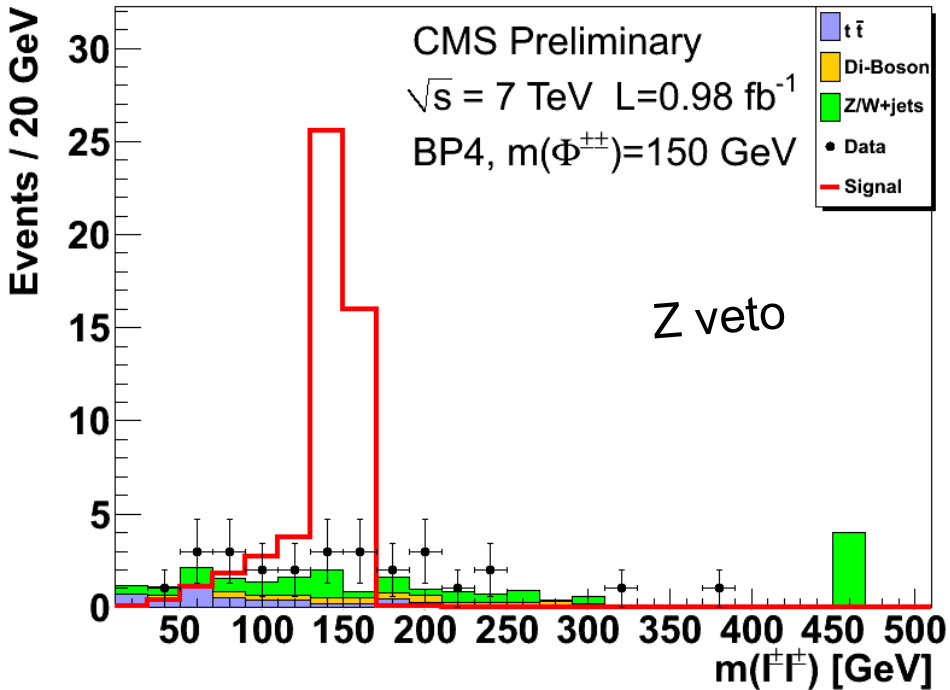
$$\Delta N_{BG} = 1/\mathrm{sqrt}(N_{CR}^{Data}+1)$$

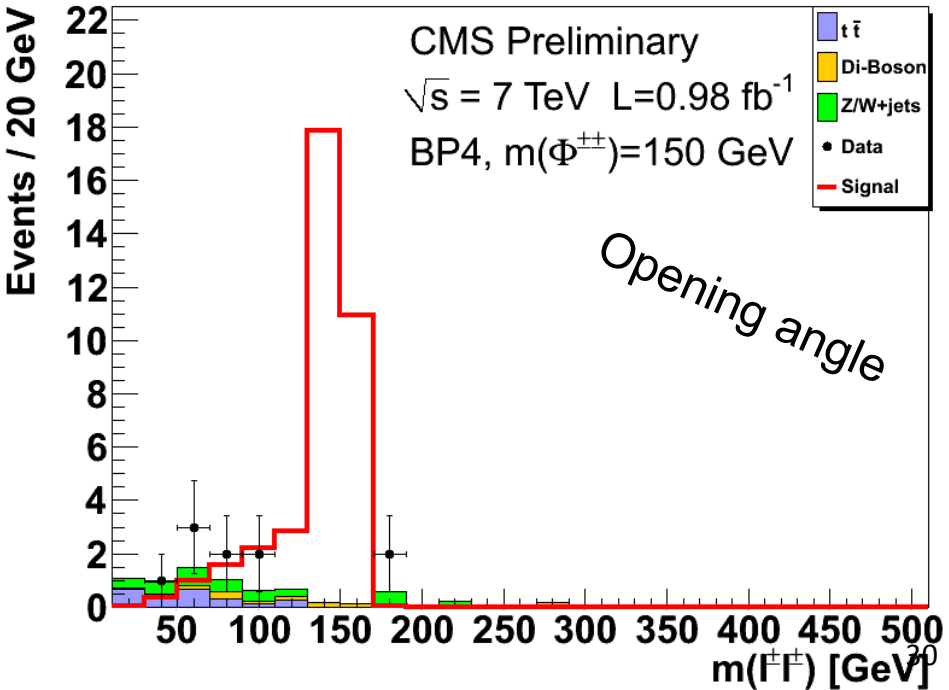
- If not enough statistics available in SR or CR the MC statistical uncertainty is used and a 100% error is attached



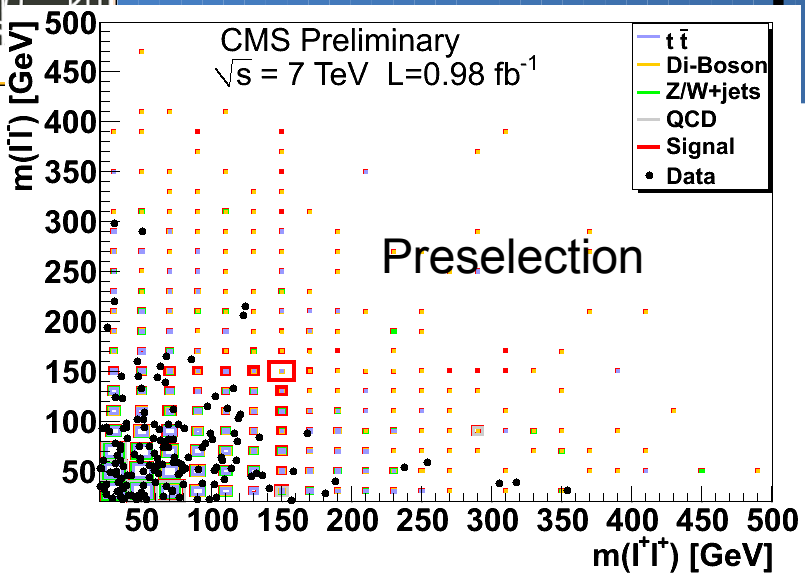

CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ++)=150 GeV
tt̄
Di-Boson
Z/W+jets
Data
Signal
ΣpT
Events / 20 GeV
m(l±l±) [GeV]

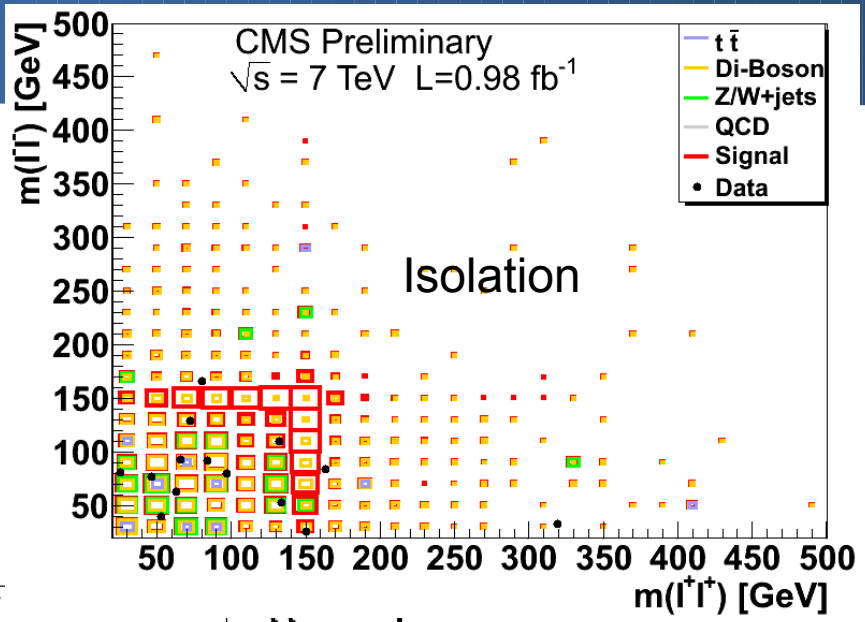

CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ++)=150 GeV
tt̄
Di-Boson
Z/W+jets
Data
Signal
Isolation
Events / 20 GeV
m(l±l±) [GeV]

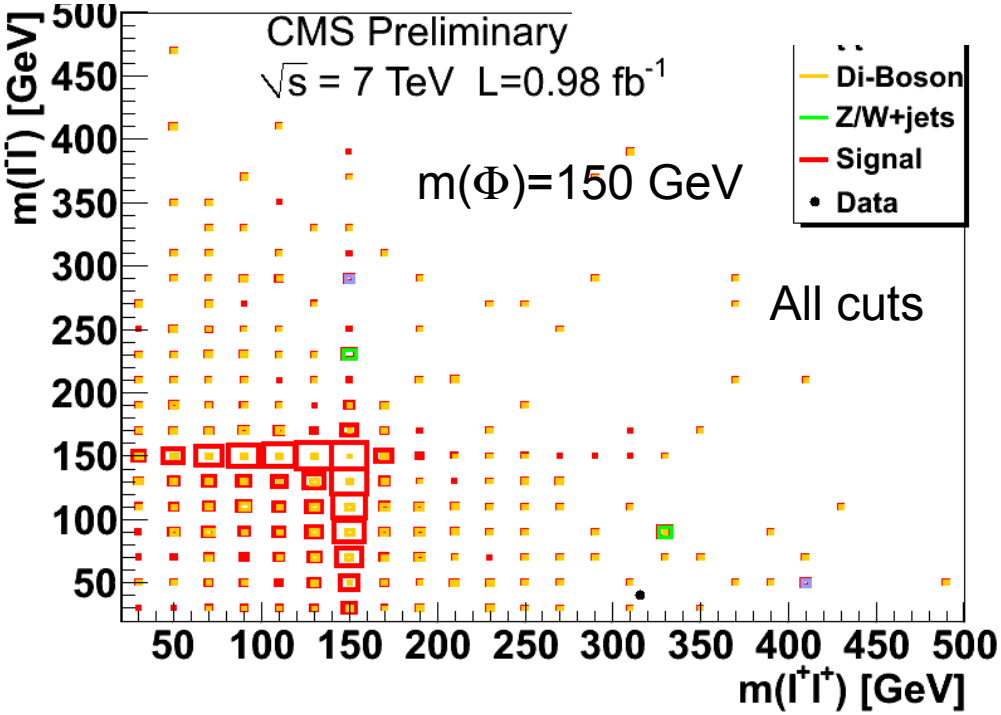

CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ++)=150 GeV
tt̄
Di-Boson
Z/W+jets
Data
Signal
Z veto
Events / 20 GeV
m(l±l±) [GeV]


CMS Preliminary
√s = 7 TeV L=0.98 fb-1
BP4, m(Φ++)=150 GeV
tt̄
Di-Boson
Z/W+jets
Data
Signal
Opening angle
Events / 20 GeV
m(l±l±) [GeV]

Four lepton final state







Systematic uncertainties

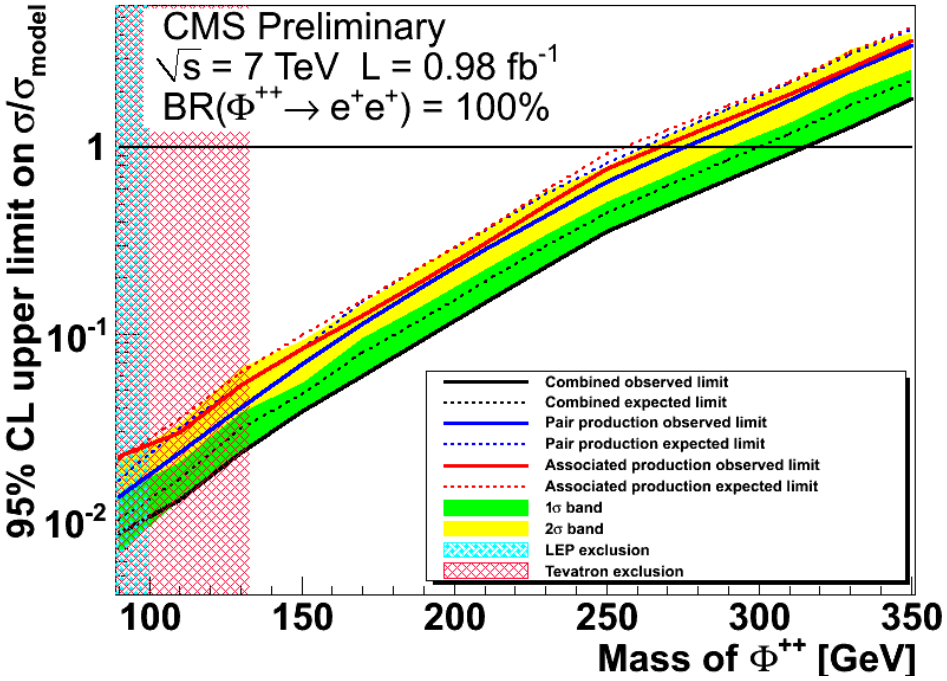
Source	Uncertainty
Lepton ID+RECO+Isolation+k-factors (e and μ unified)	2%
Tau jet ID+RECO+Isolation	8%
Trigger + primary vertex finding	1.5%
Signal cross section	10%
Luminosity	6%
Uncertainty on α, comes from PDF, QCD scale and lepton energy scale	5% / 100%*
Statistical uncertainty of signal MC	1-7%
Statistical uncertainty on observed events in control region	5-100%**

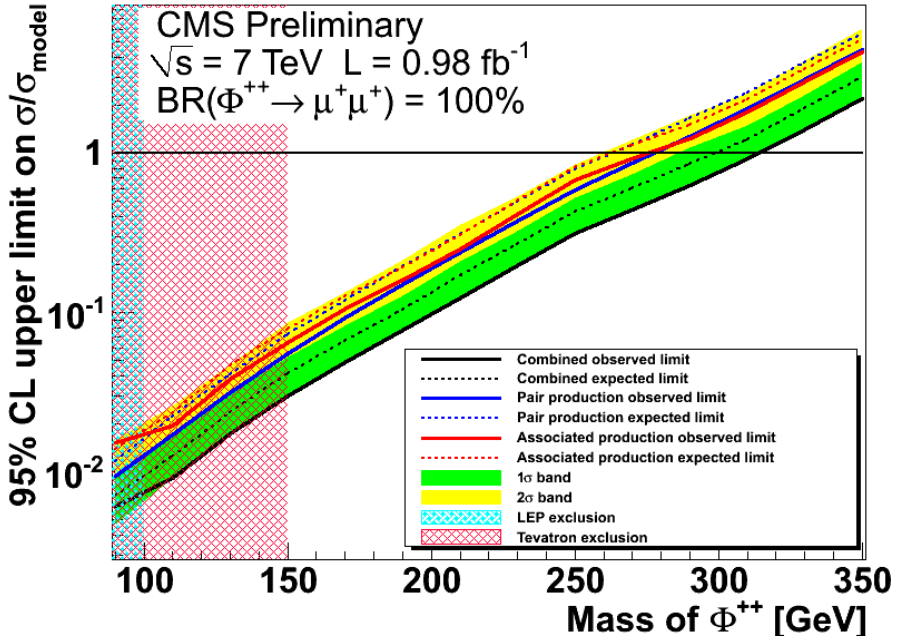
* If not enough statistics in MC are available and statistical uncertainty is used, then 100% is used as the uncertainty on the ratio

** Varies by channel, background topology and search mass

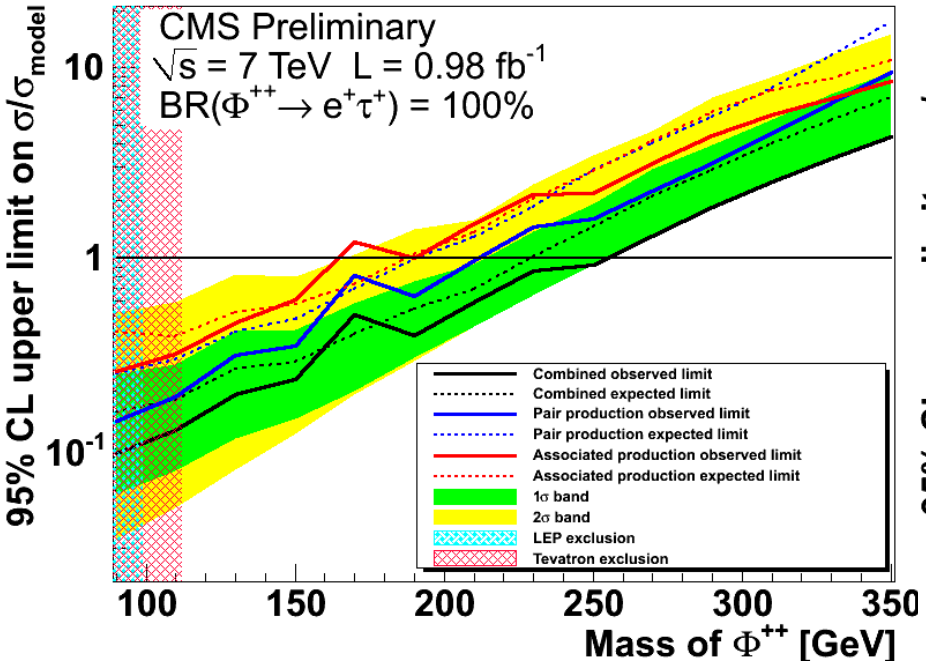
Limits are calculated with the CLs method in five categories based on lepton count and number of tau jets in the final state

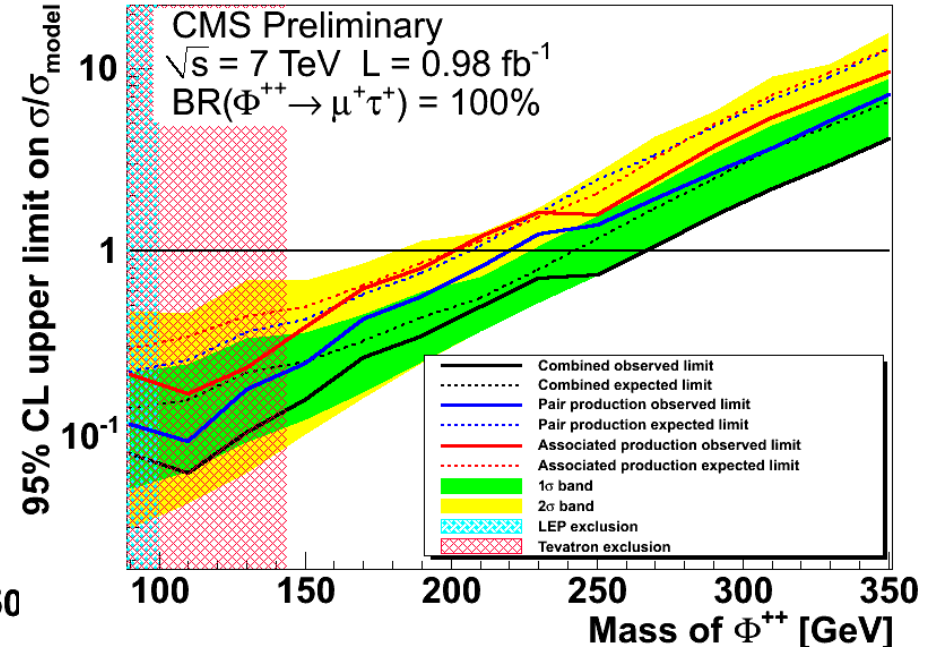
Limits


CMS Preliminary
$\sqrt{s}$ = 7 TeV L = 0.98 fb^{-1}
BR($\Phi^{++} \rightarrow e^+e^+$) = 100%
95% CL upper limit on σ/σ_{model}
Mass of Φ^{++} [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

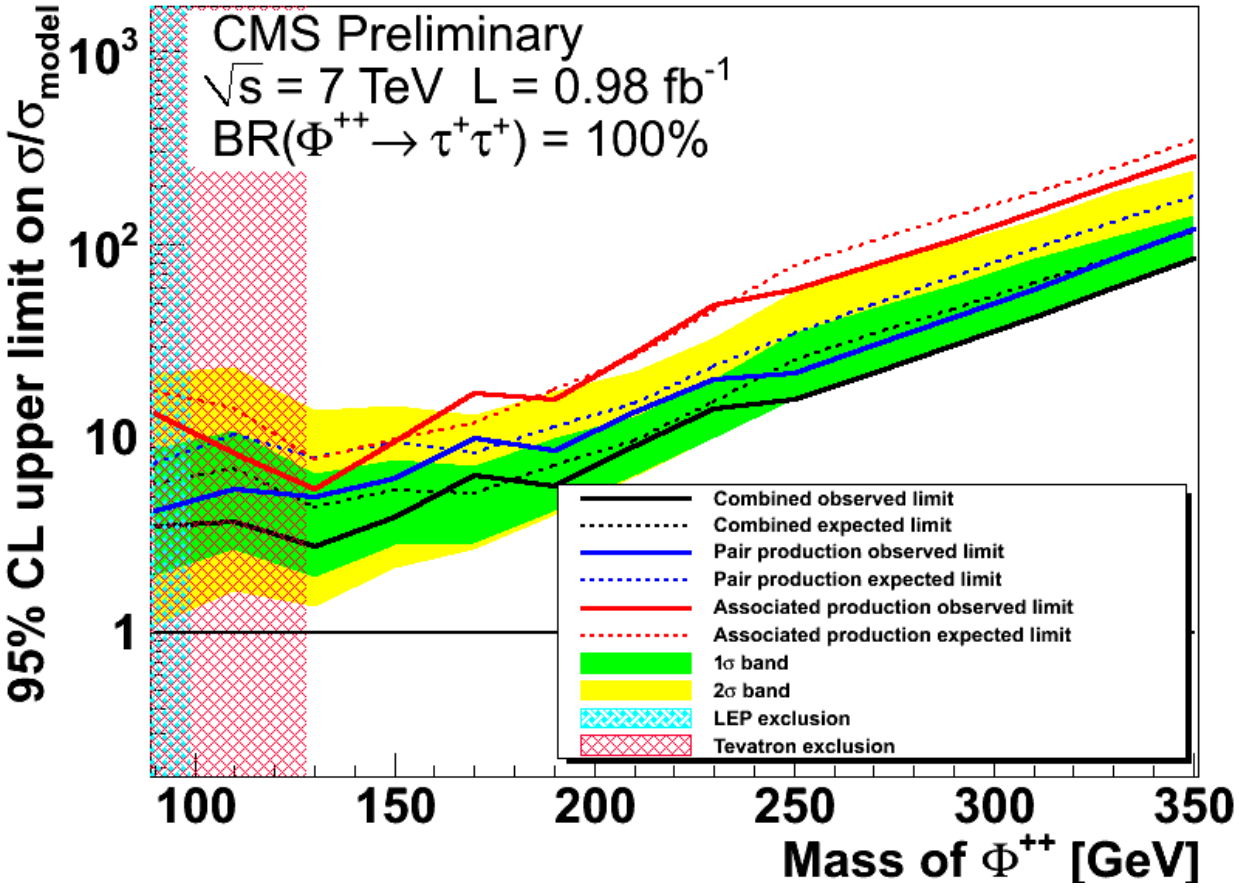

CMS Preliminary
$\sqrt{s}$ = 7 TeV L = 0.98 fb^{-1}
BR($\Phi^{++} \rightarrow \mu^+\mu^+$) = 100%
95% CL upper limit on σ/σ_{model}
Mass of Φ^{++} [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits

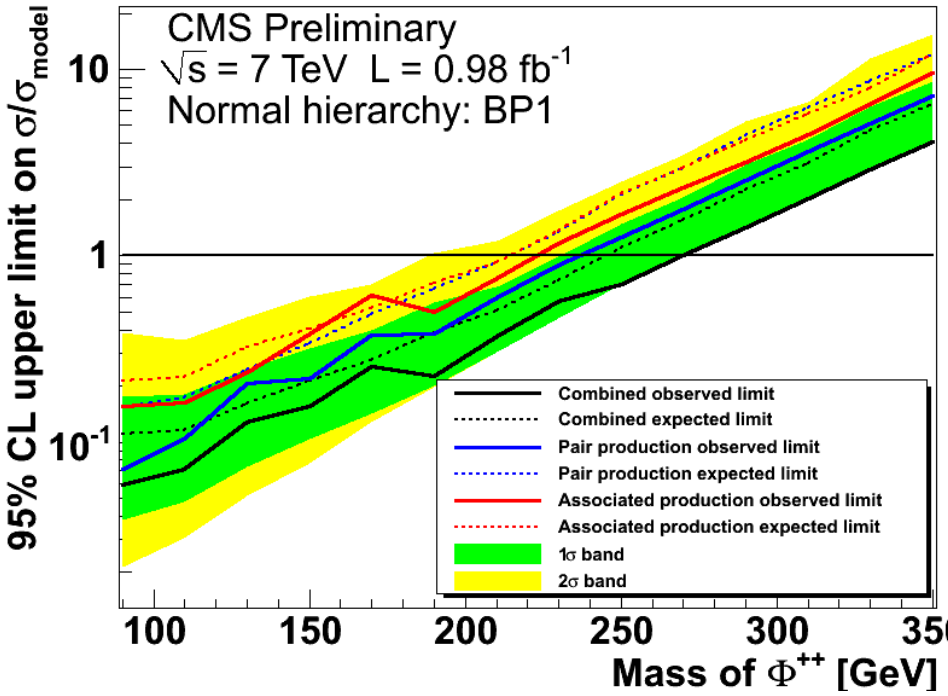

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
BR(Φ++ → e+τ+) = 100%
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

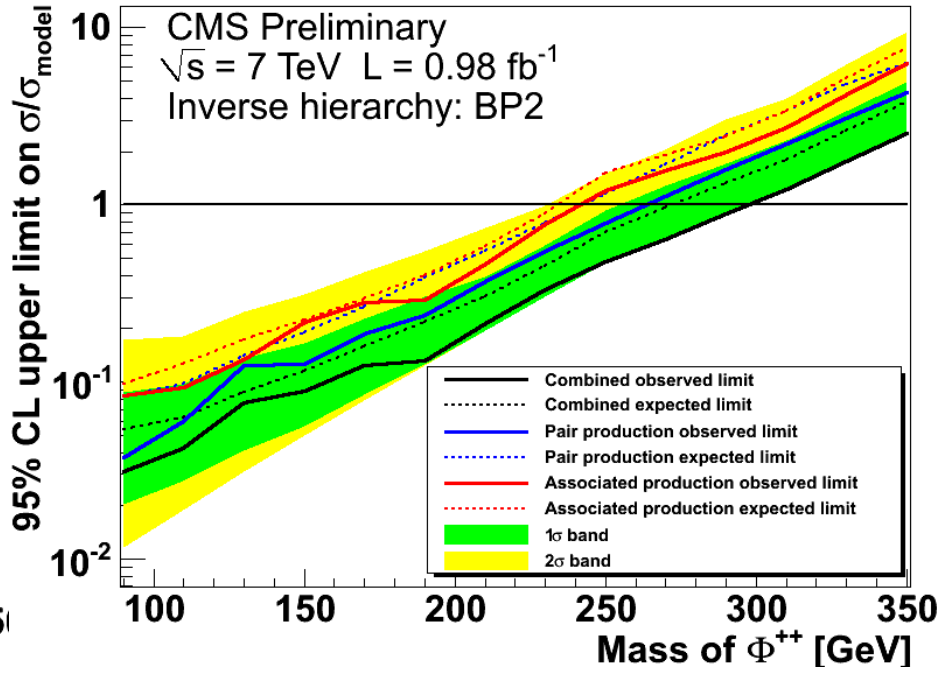

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
BR(Φ++ → μ+τ+) = 100%
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

Limits

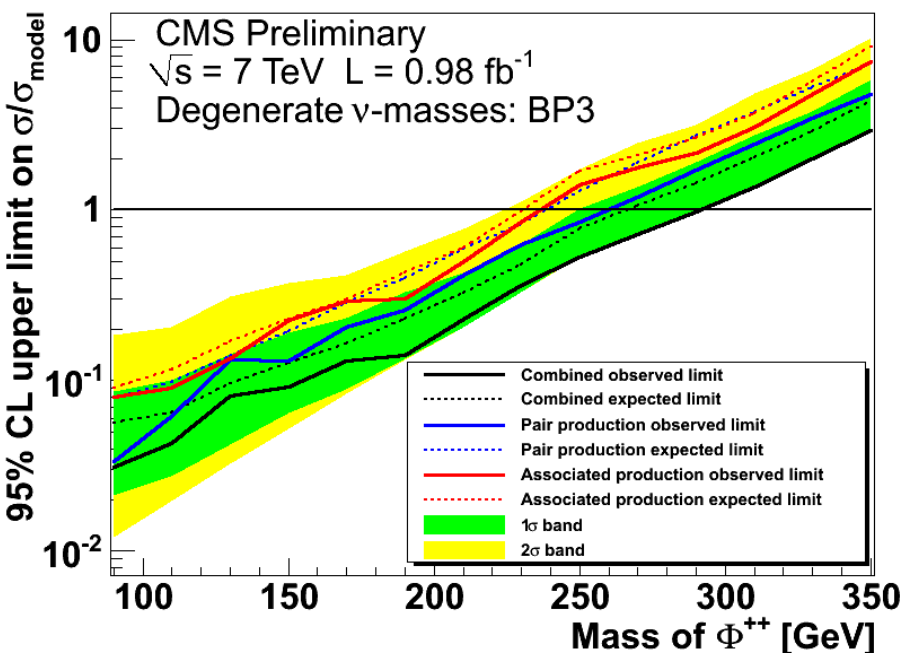

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
BR(Φ++ → τ+τ+) = 100%
95% CL upper limit on σ/σmodel
10³
10²
10
1
100
150
200
250
300
350
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band
LEP exclusion
Tevatron exclusion

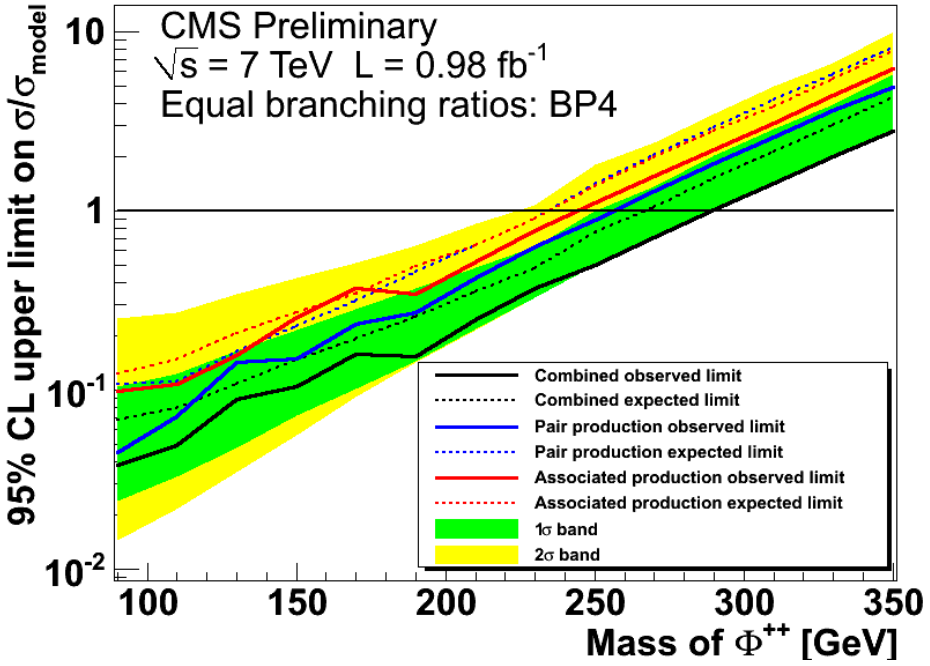
Limits


CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
Normal hierarchy: BP1
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band

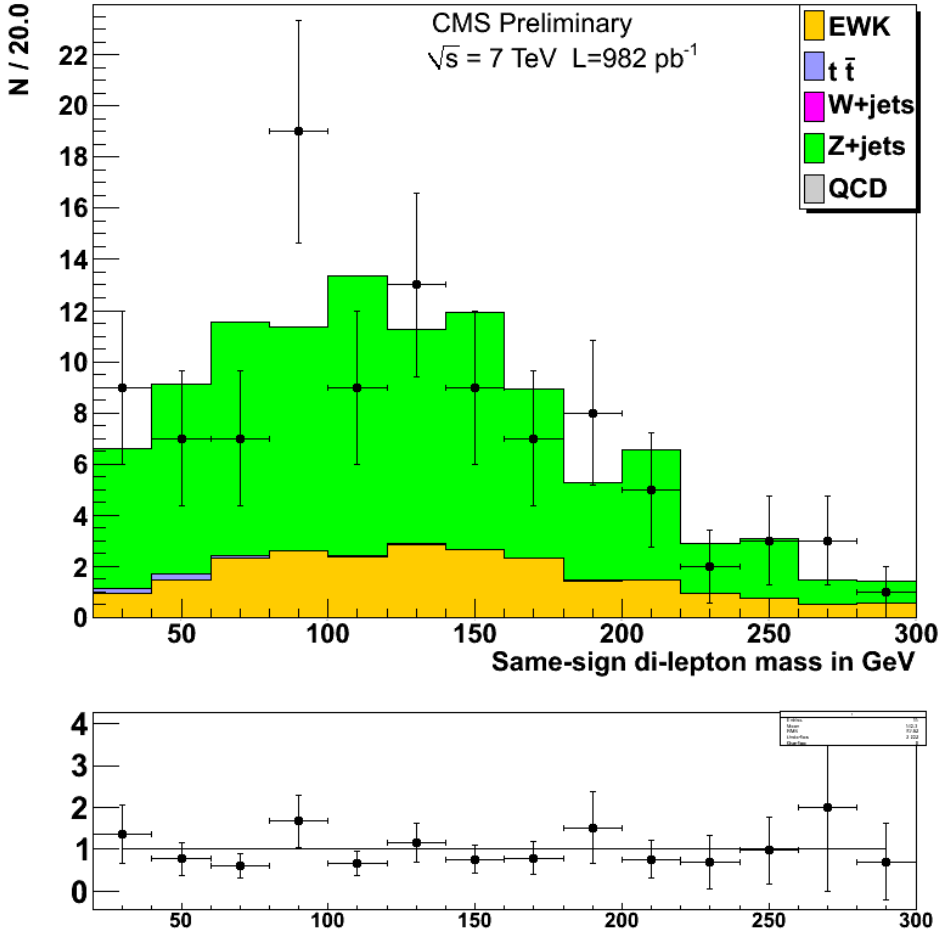

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
Inverse hierarchy: BP2
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band

Limits

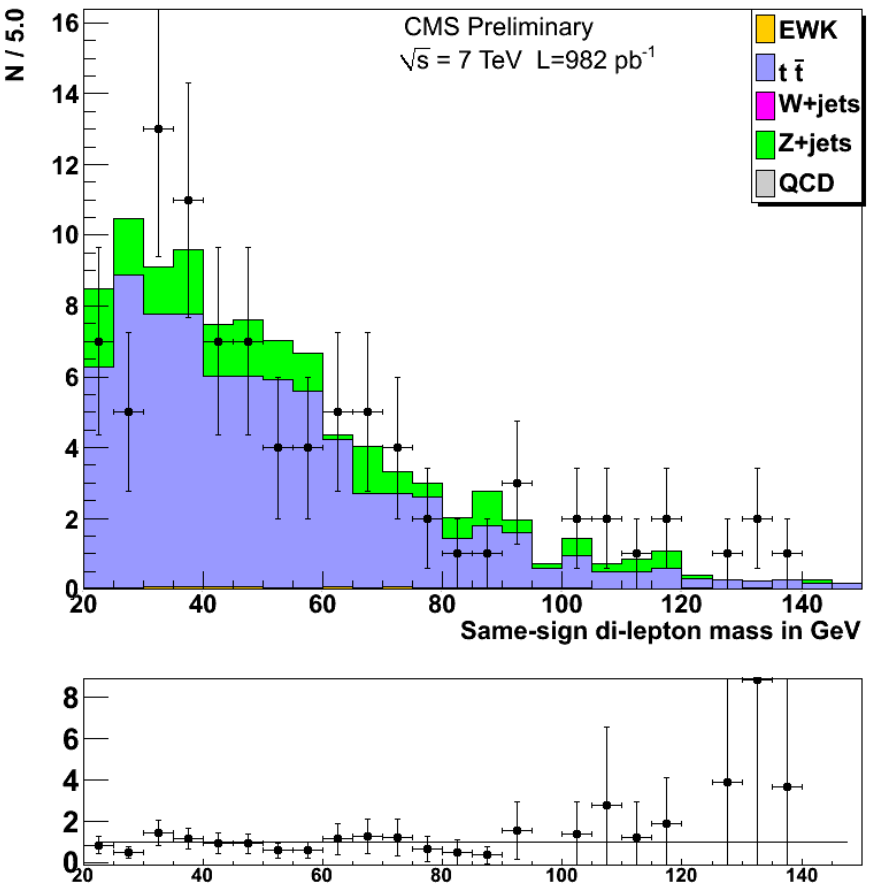

CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
Degenerate ν-masses: BP3
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band


CMS Preliminary
√s = 7 TeV L = 0.98 fb-1
Equal branching ratios: BP4
95% CL upper limit on σ/σmodel
Mass of Φ++ [GeV]
Combined observed limit
Combined expected limit
Pair production observed limit
Pair production expected limit
Associated production observed limit
Associated production expected limit
1σ band
2σ band

Background check plots



Reversed Z veto after isolation + Σp_T



Preselection, Z veto, reversed isolation + Σp_T, opening angle